If I like you, I wanna be like you!

Ballato, Laura

IF I LIKE YOU, I WANNA BE LIKE YOU!

The use of dynamic systems modeling in the understanding of friendship interactions and risk behaviors during adolescence

Laura Ballato

IF I LIKE YOU, I WANNA BE LIKE YOU!

The use of dynamic systems modeling in the understanding of friendship interactions and risk behaviors during adolescence

ISED
Institute for the
Study of Education
and Human Development

Printed by: Offsetdrukkerij Ridderprint B.V., Ridderkerk
Layout: Sara Villa
Cover drawing: Berber Munstra
ISBN: 978-90-367-5597-9 (Paper version)
978-90-367-5598-6 (Electronic version)

RIJKSUNIVERSITEIT GRONINGEN

If I like you, I wanna be like you!

The use of dynamic systems modeling in the understanding of friendship interactions and risk behaviors during adolescence

Proefschrift

ter verkrijging van het doctoraat in de
Gedrags- en Maatschappijwetenschappen
aan de Rijksuniversiteit Groningen
op gezag van de
Rector Magnificus, dr. E. Sterken,
in het openbaar te verdedigen op
donderdag 12 juli 2012
om 12.45 uur

door

Laura Ballato
geboren op 12 juni 1972
te Turijn, Italië

Promotor:
Prof. dr. P.L.C. van Geert

Copromotor:
Dr. H.A. Bosma

Beoordelingscommissie:
Prof. dr. R.C.M.E. Engels
Prof. dr. I. Granic
Prof. dr. M.C. Timmerman

To David and Leonard

CONTENTS

CHAPTER 1

INTRODUCTION

INTRODUCTION

1. Risk behaviors and peers relationships during adolescence

Adolescence is well known as a period of life marked by major changes and as a critical period of personal development. Biological changes such as increasing hormone levels, physical growth, and brain development affect the ways adolescents deal with themselves and their social surroundings, e.g., parents and friends. These changes may also increase the need of exploring new skills and experience new situations (Bosma & Jackson, 1990). Life exploring and experiencing can sometimes direct the adolescents to choose problematic pathways. Adolescence is indeed a time of increased risk behaviors such as using and dealing drugs, alcohol abuse, antisocial behavior, bullying, school dropout, and vandalism (Spear, 2000). Although not all risk behaviors can be considered as pathologies, all risk behaviors by definition contain some potential for negative outcome such as detention, AIDS infection, unwanted pregnancy, alcohol, and drugs dependency (Spear, 2000). However harmful, risk behaviors during adolescence may also have benefits. Risk behaviors may allow the adolescents to explore adult behaviors and privileges, affirming maturity and independence, and decrease stress, frustration, and anxiety (Jessor, 1977). Most of all, the benefits of risk behaviors are related to social benefits. For example, risk takers report to feel more accepted by peers, and perceive risk taking as fun (Maggs, Almeida, & Galambos, 1995). Furthermore, adolescents experimenting with soft drugs are found to be more socially competent than heavy users or abstainers (Shedler & Block, 1990). Thus, some risk behaviors can fulfill important functions and can be seen as a manifestation of an appropriate development (Engels & ter Bogt, 2001).

Recently, researchers have related the tendency to be involved in risk behaviors also to the biological changes that occur in the brain during adolescence (Crone, 2008). The adolescents' brain seems to be characterized by a biological gap. The biological gap is related to the imbalance between cognitive systems that are still in an immature stage (such as the behavior control areas e.g., the self-regulatory competence) and more developed and already "adult-like" areas such as the affective system (Steinberg, 2004). This gap may predispose adolescents to be more sensitive to immediate rewards (Casey, Getz, & Galvan, 2008); or to be more sensitive to social context pressure such as being accepted by their peers (Gardner & Steinberg, 2005).

Although conscious of the many factors that may influence adolescents' risk behaviors, this thesis focuses only on friendship relations and on how those and the involvement in risk behaviors may change during the course of time. We choose to focus on friendship relations because it is exactly during adolescence that young people begin to detach from the parental control and authority and build stronger links with the group of peers (Jackson, 1993). Peer relationships during adolescence are very complex and constitute a dynamical system. By dynamical system, we mean that the relationships are composed by components, for example positive evaluations among friends, that dynamically evolve and organize into different levels of interactions. Peer relationships can take different forms that may become more complex over time. Children's friendship relations are generally composed of only two friends, often of the same gender (the so-called dyad). In the course of time, this form of friendship expands and includes new forms of relationships with individuals of the other gender, and in some cases, it evolves into a romantic relationship. During adolescence, the individuals are also often involved in interactions with small groups of children (the so-called cliques). These groups are characterized by individuals who share the same types of values and interests and who do things together. Some adolescents are also associated with more expanded groups of individuals, also referred to as crowds, in which style and reputation seem to play a central role (e.g., the hip hoppers, the punks) (Brown & Klute, 2003).

Friends seem to be important not only for the social development of the adolescents but also because they play a great role in shaping their emotional well-being. Friendship relationships can help adolescents to increase their self-esteem and the understanding of themselves and other people (Sullivan, 1953). Friends are also a great source of support for coping with stressful events (Hartup, 1993).

Due to the social and emotional benefits adolescents receive from their friends, adolescents have the tendency to spend a lot of time with their peers (Hartup & Stevens, 1997). During their frequent social interactions, they exchange knowledge and get in contact with new behaviors and attitudes that may in some cases include risk behaviors (Bosma & Jackson, 1990).

2. Influence and selection mechanisms from the dynamic systems perspective

Do adolescents start to interact with everybody or do they actively choose with whom they wish to be friends? According to many empirical findings, the second option seems to be the right one. In fact, researchers have found that adolescents choose people with similar interests, attitudes and behaviors as friends (Bauman & Ennett, 1996; Cairns & Cairns, 1994; Cohen 1977; Ennett & Bauman,1994; Kandel, 1978). The tendency of adolescents to affiliate with similar peers has been described and conceptualized as homogeneity (Cohen 1977; Kandel, 1978). Homogeneity means that friends tend to display similar behaviors, that is adolescents who are friends tend to be similar in their attitudes (e.g., clothing style, music preference, political tendency, etc.) and their behavior (e.g., smoking, drinking, sport, etc.).

In recent years, researches have empirically showed that the observed similarity between adolescents and their friends is mostly due to the tendency of individuals to select like-minded friends (selection process), as well as to the influence that friends have on each other (influence process). These two mechanisms are thought to unfold in two stages. In a first phase, the adolescents select each other based on a preference for individuals with similar behaviors. In a second phase, the adolescents increase their involvement in these behaviors by influencing each other through modeling or reinforcement (Bauman & Ennett, 1996; Burk, Steglich, & Snijders, 2007; Engels, 1998; Houtzager & Baerveldt, 1999; Kirke, 2004; Kiuru, Burk, Laursen, Salmela-Aro, & Nurmi, 2010; Popp, Laursen, Kerr, Stattin, & Burk, 2008; Steglich, Snijders, & Pearson, 2010; Urberg, Luo, Pilgrim, & Degirmencioglu, 2003).

This thesis is an attempt to make a further step in the understanding of the onset of homogeneous behaviors among adolescent friends. The primary goal of this thesis is the understanding of the dynamical properties of peer influence and peer selection mechanisms and how these work and develop over time and on different developmental time scales (e.g., now versus over a year). In other words, we wish to disentangle the properties of influence and selection mechanisms and explain how a repeated application of a particular mechanism or process (e.g., friendship interaction) can lead to the formation of particular pattern of peer influence. In short, this thesis wishes to answer the following questions: *How do friends promote changes in adolescents' attitudes during short-term interactions and over time co-adopt their own behaviors towards the one of their friend?* We tried to reach our goals and answer our questions by using the dynamic systems approach. This innovative and flexible approach provides theoretical and methodological tools for explaining the processes that create and maintain developmental relationships and to study change and stability that characterize adolescence. The focus is on the interactions and not (primarily) on separate characteristics and behaviors. Rather than searching for linear causal relations (by using linear statistical models), a dynamic systems approach allows researchers to account for non-linear and recursive relations, which are typical of real-world complex networks—like the adolescents' social networks (see for a review: van Geert, 2003, 2008; Steenbeek & van Geert, 2005, 2007).

Typically, human development is also characterized by various phase transitions, and adolescence can be seen as one of these (Granic, Dishion, & Hollestein, 2003). Phase transitions have been described as periods in which individuals are more prone to change and in which systems come across moments of disequilibrium (Thelen & Smith, 1994). During a phase transition, an individual can easily change and reorganize his previous relations and start to search for new partners of interactions. Due to their sensitivity for changes, phase transitions are interesting moments to study how properties change over time. Indeed, phase transitions may be used to capture the inclination and the behaviors of an individual before and after a change has occurred. In this way, they may provide relevant information on the mechanisms that have stimulated the change.

Our research design also includes a transition phase. Since we sought to capture the behavioral profiles of adolescents before and after a new friendship was formed, we collected our data at the end of the second year of high school and then again at the beginning of third year. Between these two moments, classrooms are remixed because the students need to choose specific tracks and move to higher grades. Therefore, at the beginning of their third year of high school, students could end up with classmates they did not previously know or with whom they had no relationship. These two measurements were followed by two other measurements, leading to a total of four measurements in a year of the behavioral profiles and the friendship relations of adolescents. In this way, we were able to track the adolescents' developmental changes in a relatively short period of time.

Prior to the data collection, we conducted a pilot study. The main aim of the pilot was to asses the perception and the experience of teachers and students of our sample concerning risk behaviors. Since this phase has been considered as a preparation for the project, we paid considerable attention to the specific situation of the schools involved (e.g., involvement of risk behaviors of the students, major signs of risk behaviors, and effectiveness of service for problematic students). Furthermore, the pilot study helped us to build a strong relationship with the school management team. At last, we also used the results of the pilot to specify which type of students were more involved in risk behaviors. Based on this information we selected the classes for the next phases of the project. The pilot sample consists of 26 teachers and 41 students (20 female, 21 male; age range: 14-18). This study was conducted at the Ubbo Emmius school community (dependences are in Stadskanaal, Veendam and Winschoten) and the Gomarus College. These schools are secondary schools in the province of Groningen that serve students from the common core curriculum (in Dutch "onderbouw") to specific tracks: Pre-university education (in Dutch VWO), senior general secondary education (in Dutch HAVO) and prevocational education (in Dutch VMBO). In order to collect the data we used a semi-structured interview (one version for the teachers and one for the students). We analyzed the outcomes of the interviews by means of a qualitative analysis procedure. The results of the interviews showed that both the students and teachers perceived risk behaviors as something dangerous that can have negative consequences but can also serve as a way to experiment. The way to describe risk behaviors depended on the level of the involvement of the persons interviewed: Risky students perceived risk behaviors as a personal choice (e.g. something you may decide yourself to do) compared to the well-behaved age mates. Teachers and students gave also concrete examples of risk behaviors, such as substance use, deviant behaviors, risky driving, school misconduct, and sexual behavior. These are classical examples of risk behaviors. However, the teachers added some new examples to the list, like manipulative behaviors and general things such as "deviating from the main stream" (in Dutch "uit de boot vallen"). For both teachers and students, not all risk behaviors are effectively seen as risky. Frequency and quantity of the risk behavior performed make a difference, e.g., drinking alcohol sometimes is less risky than drinking alcohol every day. Both teachers and students nominated family problems, wrong education style and friends as the critical factors that may lead to the beginning of a risk behavior. In addition, personality characteristics such as insecurity, loneliness, curiosity, depression, being cool (in Dutch "stoer") may enhance the involvement in risk behaviors (for a complete description of the results, see van Eerde, 2005).

Although the teachers and the students did not mention all the possible predictors of risk behaviors, in our view they were fully aware of the main factors that may influence risk behaviors. However, they were not able to formulate a comprehensive theory and specify mechanisms and processes. Often, also researchers have spent more energy and time in trying to define the factors that influence risk behaviors (e.g., Jessor, 1977) than in formulating a dynamical theory that describes the mechanisms and processes that may explain the workings of these factors and how their effects change over time. Due to the lack of studies about mechanisms and processes, we still do not know much about the mechanisms by which peer interactions "play out" in successive social-developmental ecologies and about the conditions under which peer interactions may be related to an increase in risk behaviors over time. Only if we understand how phenomena unfold on short- and- long-term developmental time scales, we can speculate about the processes that underlie a complex phenomenon such as peer influence.

This thesis attempts to suggest new ways of how to study developmental properties and mechanisms over time. The new method that we propose is a multi-level approach (in the non-statistical sense of the term) that can be summarized in the following three steps:

1. The formulation of a conceptual framework
2. The translation of the theory into a mathematical model of a dynamic system
3. The validation of the theory with empirical data

By combing these three levels of analysis (i.e., theoretical, mathematical and empirical), we wish to propose a dynamical theory of friendship interactions and risk behaviors during adolescence. The theory should ultimately be able to explain the formation of influence and selection processes over time.

3. Outline of the dissertation

To summarize, this thesis focuses on understanding how influence and selection mechanisms develop over time in order to form a stable pattern of behaviors such as homogeneity of risk behaviors among friends. This thesis is divided into six chapters.

In chapter 2, we use the dynamic systems approach to understand the dynamics of selection and influence processes and the emergence of homogeneity of behaviors among friends. Specifically, we present a conceptual framework for explaining the relationships between friendship and risk behaviors in adolescence. The framework focuses on selection and influence mechanisms and their components as they operate during the time span of underlying developmental change.

In chapter 3, we develop a mathematical model in order to simulate the dynamic theory described in the previous chapter. The model describes in mathematical terms how real-time selection and influence processes work together and relate to long-term processes such as homogeneity or the increase or decrease of risk behaviors.

In chapter 4, we show which empirical phenomena the model is able to reproduce and we present the results of the dynamic model simulations in relation with the theoretical findings. Specifically, we present five hypotheses related to the development of homogeneity among agents and the onset of influence and reinforcement processes. The simulations with the mathematical model show that the model is able to reproduce the predicted outcomes.

Chapter 5 presents the results of the empirical study. First, the empirical study aims to understand how and if similarity changes over time. In order to reach this goal, the following questions will be addressed: *Are friends more similar than non-friends? How does similarity change during the course of one year?* The last part of the empirical study aims to confirm the similarity/selection hypothesis by answering the following question: *Do friends have similar behaviors before their friendship is formed?*

To conclude, chapter 6 provides a summary of the findings and a general discussion.

CHAPTER 2

A DYNAMIC THEORY OF FRIENDSHIP INTERACTIONS AND RISK BEHAVIORS DURING ADOLESCENCE: DYNAMICAL ASPECTS OF INFLUENCE AND SELECTION MECHANISMS

INTRODUCTION

Adolescents have many opportunities to meet other peers and spend a lot of time with them. In interacting with their friends adolescents may come in contact with new experiences and behaviors. Sometimes, the need for experimenting can lead adolescents to start or increase the involvement in what researchers have called "risk behaviors" (Bosma & Jackson, 1990; Erikson, 1968). These behaviors are considered risky because they can compromise the present or future physical and mental health of the individual (Jessor, 1992; Jessor & Jessor, 1977). Examples of these behaviors are: Substance use, oppositional behavior, school dropout and unprotected sex (Jessor & Jessor, 1977). These behaviors are typical of the adolescent years and mostly take place in the company of the peers (Boyer, 2006; Cairns & Cairns, 1994; Spear, 2000).

Scholars have revealed that the involvement of adolescents in risk behaviors strongly resembles that of their friends. Adolescents who have friends who are involved in risk behaviors are themselves more likely to be involved in risk behaviors (Dishion & Loeber, 1985; Elliott, Huizinga, & Ageton, 1985; Hawkins, Catalano, & Miller, 1992; Jessor, 1992). For example, one of the most important correlates of adolescent smoking behavior is the smoking behavior of friends (Wang, Fitzhugh, Westerfield, & Eddie, 1995). Longitudinal studies have also indicated that having friends who engage in risk behaviors is the strongest predictor of the adolescents becoming involved in risk behaviors (Conrad, Flay, & Hill, 1992; Harris, 1998; Urberg, Shyu, & Liang, 1990). In view of these results, researchers have concluded that there is a strong homogeneity in risk behaviors between peers, and hence that peer influence is contributing to this homogeneity (Hawkins *et al.*, 1992; Jessor, 1992; Wang *et al.*, 1995).

Recently, scholars have included selection as an explanatory factor for the formation of homogeneous behaviors among friends. Several recent and methodologically advanced studies, which have both measured peer influence and peer selection effects, have found that both factors influence adolescent risk behaviors (see for examples: Burk, Steglich, & Snijders, 2007; Engels, Knibbe, Drop, & de Haan, 1997; Ennett & Bauman, 1994; Hoffman, Monge, Chou, & Valente, 2007). In view of these new studies we believe that it is neither peer influence nor selection but influence and selection together that contribute to the formation and the increase of homogeneity of behaviors among adolescents. We also believe that what researchers have so far seldom explained is how influence and selection work and develop over time. In other words, we still do not know enough about the mechanisms that underlie peer influence and selection and how these mechanisms change and unfold on different developmental time scales, i.e., short-term and long-term time scales. Why this distinction? The short-term time scale is related to what happens "now" in the action and reaction chain of social interactions. An example is the event in which two adolescents meet for the first time at the first day of school and express a preference for each other by going together for lunch or back home (Jackson, 1987). Thus, short-term development refers to a real-time action (i. e., the micro level of development). Instead, the long-term time scale refers to the long-term change of the variables that govern the short-term events (e.g., the preference for each other during the first day at school). For example, after many interactions, let's say one year of school, the two adolescents can develop and form a stable friendship dyad. The short-term and long-term development time scales are interrelated and only the understanding of both gives a sufficient explanation of the phenomena under study (Steenbeek & van Geert, 2007; van Geert, 2008). In simpler words, what happens now influences what will happen in the future. Only if we understand how the mechanisms unfold in both time frames we can have a complete understanding of the phenomena we are interested in.

Before going into the details of our study, we would like to clarify and give a definition of the main theoretical terms that we will use in this chapter: Homogeneity, peer influence and selection mechanisms. Homogeneity means that friends, in the course of time, tend to display similar behaviors, that is adolescents tend to become similar in their attitudes (e.g., clothing style, music preference, political tendency, etc.) and their behavior (e.g., smoking, drinking, sport activities, etc.) (Cohen 1977; Kandel, 1978). By peer influence scholars mean direct peer pressure (i.e., direct attempts to change the behavior of a friend) as well as other social processes (e.g., imitation) with peers that involve an influence from peers to the adolescent in question (Arnett, 2007). In both cases, the influence is believed to be from the friends to the adolescent and the resulting homogeneity is believed to be the product of the friendship (Arnett, 2007). In this paper, we are going to present a new definition of peer influence and clarify the difference with other imitation mechanisms such as reinforcement. The notion of selection mechanism implies that adolescents select friends who have similar behaviors; more specifically, the pre-existing similarity is the cause of the establishment of the friendship (Bauman & Ennett, 1996; Cohen 1977; Engels, 1998; Ennett & Bauman, 1994; Kandel, 1978).

The present chapter tries to reach two aims. First of all, we aim to present a conceptual framework for explaining the relationships between friendship and risk behaviors during adolescence. The framework focuses on selection and influence mechanisms and their properties as they operate on different developmental time-scales. In particular, the framework aims to explain how the properties of selection and influence work together to generate different and stable developmental outcomes, such as friendship and homogeneity of risk behaviors. Secondly, the conceptual framework is used as basis for building the dynamic systems model that we will present in chapter 3 and 4.

In the following sections, we will explain our conceptual framework of friendship and risk behaviors by first describing the basic features of the dynamic systems perspective (section 1) and then proceed by presenting our framework in general terms (section 2) and by specifying the components of the theory (section 2.1 to 2.6).

1. The dynamic systems perspective

1.1 The dynamic systems approach: General aspects

The body of literature and the number of researches inspired by the dynamic systems approach is now rapidly growing. We can find examples of this application in the study of different areas of development, such as emotional development, parent-child interactions, self and identity, social interaction, attachment, and antisocial development (see for examples: Bosma & Kunnen, 2001; Fogel, 1993; Granic, 2000; Granic & Patterson, 2006; Kunnen & Bosma, 2000; Lewis, 2000; Lewis & Granic, 2000; Lichtwarck-Aschoff, van Geert, Bosma, & Kunnen, 2008; Olthof, Kunnen, & Boom, 2000; van Geert, 1996; Steenbeek & van Geert, 2005, 2007, 2008). More recently, dynamic systems researchers have also addressed questions related to peer influence and interactions with friends (see for examples: Dishion, Nelson, Winter, & Bullock, 2004; Granic & Dishion, 2003). However, dynamic systems theory and methods are at present only rarely used in the study of socialization processes in adolescence. Nevertheless, we assume that it is one of the most appropriate methods to gain new insight into the complex dynamics of interaction among friends and risk behaviors during adolescence. First of all, the dynamic systems approach provides an appropriate means for studying the transitional nature of this phase of life. Adolescence is a time of developmental transition, when critical changes occur in several domains, such as the biological, cognitive and social domains (Bosma & Jackson, 1990; Granic, Dishion, & Hollestein, 2003; Spear, 2000). The typical changes and discontinuities that characterize adolescence are explained in dynamic systems thinking by using the notion of phase transition. Phase transitions have been described as periods in which systems come across moments of disequilibrium. During a phase transition, a system can easily break down its stable patterns and let novel forms emerge in their place. These phases are necessary in order to let systems change and reorganize (see for a review: Thelen & Smith, 1994). To better understand the definition of phase transition, we will give a concrete example. Children at the end of their elementary school are going through a social phase transition[1]. After years of established relationships with teachers and students of the elementary school (i.e., period of stability), the children will meet other children who can bring them in contact with new behaviors, attitudes and life style (new components in the system will be added; i.e., period of instability). Only through the destabilization of the old relationship patterns, new relationships can arise and eventually stabilize into new and updated forms. In other words, only after a certain period of time the new relationships with students and teachers will stabilize and will take specific forms.

As we can see, the dynamic systems approach uses new terminology and new concepts, by means of which it offers a different view on socialization processes. Moreover, it proposes dy-

[1] Phase transitions are not only social. We can find examples of biological, cognitive and emotional phase transitions (see for example: Ball, 2004). However, our study focuses on friendship, thus our examples refer mostly to social phenomena.

namically oriented theoretical frameworks. Contrary to traditional models, the dynamic systems approach focuses on finding the basic properties of the interaction processes and on explaining how the different properties of interaction processes work together as forces that influence each other over time (see: Steenbeek & Van Geert, 2005, 2007; van Geert, 2008). Stated differently, the dynamic systems approach focuses on change over time, by introducing explanatory mechanisms of change. The dynamic systems approach also emphasizes that behavior should not be conceived of as a simple unidirectional pattern of cause and effect but as an iterative or recursive process. In fact, the recursive or iterative aspect is one of the more innovative and useful concepts of dynamic systems in the study of socialization processes. Interaction or recursiveness means that the current state of the interaction is the starting point of the following state of the interaction. After each interaction, some of the variables that characterize the interaction change. The changed system is the starting point of a new social situation and new interaction possibilities, and thus social interaction is construed as an iterative process (Thelen & Smith, 1994; van Geert, 2003; van Geert, 2008). Take as example two adolescents who meet for the first time. The two adolescents are both smokers and have an average level of popularity. Furthermore, they both like punk music and attending live concerts. At the end of the day, they express a preference for each other by going to drink a beer together in their favorite punk club. During their first interaction, they start smoking cigarettes and drinking beers and in the meantime they are telling stories about the last concert they saw, they have fun, and they are enjoying their time together. Their next interaction (let's say the second day of school) will be the product of this first interaction and it will be based on the experiences and emotions felt during the first interaction. If, in the course of time, their interactions and their evaluation of these interactions will stay positive, a stable form of friendship is likely to arise and the behaviors of the two adolescents will, eventually, become homogeneous, i.e., similar to one another.

In addition, from the dynamic systems point of view the activity of the properties involved in a social interaction is more than the simple sum of all the properties. That is, social interaction is characterized by non-linearity and self-organization (Thelen & Smith, 1994; van Geert, 2003; van Geert, 2008). Self- organization means that in complex adaptive systems (e.g., an adolescent and his friend), order emerges spontaneously from the non-linear interactions among the components of the system. The new patterns that emerge from the interaction are in general not predetermined and arise without instruction or programming. The new patterns emerge spontaneously from the system itself and do not have to be imported into a system from outside (Lewis, 2005; Thelen & Smith, 1994). When a new complex pattern has emerged, the system tries to maintain it and tends to move towards a stable form of equilibrium state, for example a stable friendship dyad. In dynamic systems terms, these stable patterns that spontaneously emerge are known, as "attractor' states" (note that an attractor state can also consist of a cycle of states, or a pattern of states). An attractor is a state towards which the system is automatically drawn, given a broad range of possible starting points and conditions (e.g., preference for the interaction partner, similarity in behaviors) (Steenbeek & van Geert, 2005). Take again as example two adolescents who meet at the first day of school. At that point in time, they are not yet friends. However, after many interactions a stable form of friendship will emerge. The friendship emerges spontaneously by means of the daily interactions and positive emotions the two adolescents share. Friendship is a typical example of a self-sustaining state.

Another important advantage in using the dynamic systems approach lies in its emphasis on the notion of time and the distinction among different levels of time at which development occurs. On the one hand, we have the daily real-time action (or short-term development) that creates the conditions in which long-term processes such as friendship and homogeneity take place. Long-term development, on the other hand, creates the conditions for real time actions, by changing environments, valences of environments and the means of realizing goals. As we already pointed out, the long-term processes of development and the short-term process of action are intimately dynamically related (Steenbeek & van Geert, 2008; van Geert, 2008) and only the understanding of both give a sufficient explanation of phenomena at issue.

As we can see, the dynamic systems approach can offer innovative ways to theoretically reframe old topics and phenomena. Furthermore, the innovative dynamic systems ideas have been translated into alternative methodological tools. We will now briefly explain some of the main methodological principles of the DS approach by first describing what we mean by a system, then by specifying what dynamic systems mathematically means and by giving examples of some dynamic systems techniques.

1.2 The methodological principles of the dynamic systems approach

A system is a combination of variables that are related to each other and act as a unit (Norton, 1995). A system is dynamic if at least one variable of the system changes over time. Weisstein (1999) defines a dynamic system as "a means of describing how one state develops into another state over the course of time" (p.501).

A dynamic system describes the current state of the system, i.e., the variable(s)' current value, as a function of their preceding state(s) (van Geert, 2008). By a variable's current value, we mean for example the level of the involvement in risk behaviors by an adolescent and his friend. These two variables form the state of the system. In this case, we have a system composed of more variables, that is, a coupled system. A dynamic model of the involvement in risk behaviors by an adolescent (x) and his friend (y) can be mathematically expressed in the following form:

$$x_{t+1} = f(x_t, y_t)$$
$$y_{t+1} = g(x_t, y_t)$$

This model is recursive or iterative, and coupled. It states that "the value of x at *t + 1* is a function (the f in the equation) of x at time t and of y at time t" (and a similar statement for yt). If x and y are the current values of the involvement in risk behaviors by the two adolescents, the equations describe a function that transforms x_t and y_t (the values of the involvement at the present time) into x_{t+1}, y_{t+1}(the values of the involvement at the next time), and then transform these values into x_{t+2}, y_{t+2} into x_{t+3}, y_{t+3} and so on (the value of the involvement at$_{t+1}$, into the value of the involvement at t_{t+2}, etc.). This equation can describe the change in the involvement in risk behaviors of two adolescents at the beginning of the school year (x_t, y_t) till the end of the school (x_{t+3}, y_{t+3}), with +1 meaning the period of time between two events as e.g., one week. This succession of xs and ys is what is meant by the iterative or recursive nature of the system (Steenbeek & van Geert, 2005).

The dynamic systems equation refers not only to states (x, y values of the involvement in risk behaviors) but also to functions (f, g). The functions f and g are also referred to as the evolution term(s) or evolution "law(s)". That is, it is important that they represent some rule of change (van Geert, 2008). The functions refer to the amount of force a variable executes on another variable and thus to the amount of change it causes in the other variable (e.g., increase or decrease). For example, the strength of the influence exerted by a popular adolescent is greater than the strength exerted by the non-popular ones. Another way to explain a function is to describe it verbally as a rule that makes the values in the dynamic equation change (e.g., if we are similar, I will increase my preference for you) (Steenbeek & van Geert, 2007, 2008).

Although developmental psychologists should primarily be interested in the study of how phenomena change, many researchers in this field mostly use static equations for modeling developmental change (Granic & Hollestein, 2003; Howe & Lewis, 2005; van Geert & Steenbeek, 2005). Static equations look as follows: $X_t = f(a, b, c, d)$. This equation simply states that the value of a particular outcome (e.g., X= level of involvement in risk behaviors) is a function of the value of other variables such as parenting style (a), parental monitoring (b), conventional activities (c), and involvement with deviant friends (d). However, this equation does not explain *how* friendships and risk behaviors develop, change and/or remain stable over time. Therefore, in this respect static equations are limited and cannot be used for modeling unfolding patterns of behaviors over time (Granic & Hollestein, 2003; van Geert, 2008).

Dynamic systems scholars have suggested alternative techniques appropriate for the study of change. Examples of these techniques are: State space grid analysis (Lewis, 1999), dynamic growth modeling (van Geert, 1994), simulation modeling (Gilbert & Troitzsch, 1999) and catastrophe modeling (van der Maas & Molenaar, 1992). All these models produce time series data, that is, predictions of successive states over time. Thus, in order to validate these models, we need time series data, which require multiple measurements over time. The interval among the measurements may vary depending on the question we wish to answer: Some phenomena may change every minute (e.g., conversation, baby crying), others need weeks or months to unfold and settle into stable forms (e.g., the habit of smoking). The frequency of the measurements should, therefore, follow the natural change of the phenomena under study (e.g., weekly or monthly assessment in the study of friendship interactions). This last observation may seem trivial, yet it is not often applied in developmental studies.

2. The conceptual framework: Friendship and risk behaviors during adolescence from the dynamic systems perspective

The social interactions among adolescents form the focus of this study. Our interest is not primarily the understanding of *what* type of behaviors the adolescents have and *what* type of behaviors their friends have. Instead, we are interested in understanding *how* friends promote changes in adolescents' attitudes and behaviors and *how* the adolescent co-adopts his own behavior towards the one of the friend, and vice versa. Young people learn about norms in their surrounding networks, during daily interactions with their family, friends and other adults. These interactions expose them to a variety of environmental influences, attitudes and behaviors. But young people are not passive. They act and react to them in different ways i.e., by adapting their behavior, influencing others or seeking other friends (Engels, 1998). Therefore, it is during daily interactions that friends acquire similar behaviors and attitudes and become, eventually, a homogeneous group. Nevertheless, there is hardly any theory that explains how things change and take form during social interactions among adolescents. In other words, we miss a theory that can explain the processes and the mechanisms that underlie social interactions and their development. This theory should provide an answer to the following questions: How do friends influence each other and in the course of time become homogeneous? We believe that the dynamic systems approach can fill in this gap and can provide us with a theory that can answer the previous question.

An important advantage of using the dynamic systems approach is that it forces the researcher to have a clear idea of the nature of the properties of the phenomenon he/she wishes to study and more particularly of the nature of the function that transforms the phenomenon (van Geert & Steenbeek, 2005). The researchers must formulate their theory of change in a precise and detailed manner. The first step is to identify the basic characteristics of the processes we wish to model. These basic characteristics represent the properties of the model. The second step is to identify the dynamic relationship among the properties and their dynamic nature. In other words, the researcher must formulate the rules (i.e., dynamic laws) that make the properties change over time (Steenbeek & van Geert, 2005; van Geert & Steenbeek, 2005).

Our conceptual framework is inspired by the work of Bauman and Ennett (1996). These authors postulate that selection plays a big role in creating similar risk behaviors among friends. Once friends are formed they may reinforce common behavior and in that sense operate as a force of reciprocal influence. Starting from this assumption, we formulate the following dynamical assumption: Adolescents become friends on the basis of their behavioral profile (i.e., similarity), preference and/or popularity, and because of mutual influence or reinforcement they co-adapt their behavioral profile in such a way that their behavioral profile, if it is positively evaluated, becomes more homogeneous. If adolescents evaluate each other negatively, the interaction is likely to end. Furthermore, we conceptualize the development of friendship and homogeneity among friends as a result of the short-term and long-term dynamics of two mechanisms: Influence and selection. Influence and selection have been decomposed into sub-properties that form our model of friendship and risk behaviors. The properties of our model are: *Risk and conventional behaviors, perceived behavior, similarity, perceived similarity, preference, mutuality, interaction (value), popularity, and evaluation*. The selection of these properties was based on the following questions: In what type of behaviors are adolescents involved (2.1.)? How do adolescents select each other (2.2)? How do adolescents interact (2.3)? How do adolescents influence each other (2.4)? Who are the most influential adolescents (2.5)? How do adolescents evaluate each other (2.6)? We found the answers to these questions in the existing literature. In the next sections each of the questions will be theoretically described.

In order to understand the connection between the properties and the proposed dynamic systems model, each description of the properties is followed by an explanation of the implementation of the property at issue in the model. The model accounts for interaction mechanisms, so it tries to clarify the question of how self-guided actions (choosing friends) and outer forces (influence by friends) work together. In the description of the model we will refer to the term agent. Agent is a model-related word that means a "simulated adolescent", who has certain goals or preferences, can perform certain acts and can retrieve certain forms of information. Every agent in the model is seen as a giver as well as a receiver of influence. The model also postulates individual differences in behaviors, personal preferences of the agents and influencing factors like popularity. Every agent evaluates the interaction with another agent and decides on the basis of this evaluation how to change his or her behavior[2]. The agents' values of the properties resemble typical adolescent values. Comparable to the real adolescent population, some agents are more involved in risk behaviors, are more popular or express a specific preference to another agent and so forth. The model simulates a real behavior, such as a discussion among friends, in the following way: The model has a repository of possible behaviors in the form of symbols (e.g., the word discussion refers to a real discussion in the real world and it is one of the many possible actions that are in the repository), based on some form of input, the model selects one of the symbols from its repository and produces that as readable output. The model works in a similar way for other agents' behaviors e.g., interactions. Furthermore, the agents need an environment to start to interact and change their properties. Our simulated environment is a classroom of a secondary high school. The behaviors, the numbers of agents and their environment resemble the empirical data we collected to validate the model (about the empirical data, see chapter 5).

In the next section (2.1), we will describe the properties that form our conceptual framework and the mathematical model and we will devote a section to the questions we previously asked.

[2] Note that in a real agent or a person this decision would be a mainly automatic or unconscious process.

2.1 In what types of behaviors are adolescents involved? Risk behaviors and other activities during adolescence

2.1.1 Theory

Although adolescents display a wide range of behaviors, risk behaviors are very typical of this age and are in fact the focus of our present study. Risk behaviors include a variety of behaviors such as substance use, school drop-out, antisocial behavior, drunk driving, and unprotected sex (Jessor, 1992; Jessor & Jessor, 1977; Spear 2000). These behaviors are considered risky because they are associated with some probability of negative consequences for the present or the future life of the individual (Jessor, 1992; Jessor & Jessor, 1977). Studies have shown that many of these types of risk behaviors emerge, increase, and eventually peak in adolescence (i.e., between 12 and 18 years of age; see for examples: Arnett, 1992, 1999; Irwin, 1993; Jessor, 1992; Spear, 2000). Studies have also shown that the majority of the adolescents engage in some sort of risk behaviors (WHO, 2002). That is, risk behaviors are part of a normal development of the western adolescents and although they can have negative consequences, they can also bring several advantages to the growing individual. For example, risk behaviors are considered a marker of independence and autonomy. They can improve social skills and let the individual experiment with different life styles and behaviors (Jessor, 1992; Jessor & Jessor, 1977). The Problem Behavior Theory (Jessor, 1992; Jessor & Jessor, 1977) emphasizes social factors (e.g., peers, or family environment) or personality factors (e.g., self-esteem) as the triggers to engage in risk behaviors. However, other studies have pointed out that the probability that an individual will be involved in risk behaviors is also influenced by cognitive skills (e.g., decision making), affective tendencies (e.g., emotional regulation), biological underpinnings (e.g., growth of hormone levels) (for a review: Boyer, 2006) and brain development (Crone, 2008). Longitudinal studies have also pointed out that for some individuals the engagement in risk behaviors is not only limited to the adolescent years but that it starts during childhood and continues during adult life (Moffit, 1993). These individuals are a minority, but they represent the most problematic adolescents. For this last group of adolescents, the positive effects of risk behaviors are soon replaced by strongly negative effects. The involvement in risk behaviors is serious and can be considered a precursor or a sign of psychopathology (e.g., conduct disorder, addiction disorder).

Even if the majority of the adolescents are involved in risk behaviors, they do not spend their time only smoking and/or drinking, other activities are also central in their daily life. A number of studies have shown that adolescents' activities may vary from highly structured (e.g., competitive sport teams, schooling that the adolescent receives) to unstructured activities (e.g., hanging around with friends). The structured activities are often directed by one or more adults and are structured by fixed rules (Jones & Offor, 1989; Mahoney, 2000). By contrast, a variety of youth leisure activities are relatively unstructured and take place without formal rules or the presence of adults (e.g., watching television, playing pc games, hanging around with peers).

Researchers have found that adolescents differ in their involvement in activities and that there is a relation between the type of activities chosen and risk behaviors. Participation in highly structured leisure activities is linked to low levels of risk behaviors, while participation in activities with low structure is associated with high levels of risk behaviors (Mahoney & Stattin, 2000). Furthermore, researchers have distinguished different types of adolescents, i.e., risky and conventional adolescents. Conventional adolescents are more involved in conventional and structured activities than risky adolescents (Jessor, 1992; Jessor & Jessor, 1977). Furthermore, conventional adolescents are less prone to change their behaviors and attitudes since they are more oriented towards conventional values, such as the values of their parents or of social institution such as school and church. For example, Marcia (1966) described these individuals as having an identity foreclosure. This identity status characterized adolescents who have not experienced an identity crisis and tend to conform to the expectancies of others regarding their present and future decisions (e.g., by choosing a school or future career that satisfies their parents' interest). Therefore, these individuals do not explore many options during adolescence.

2.1.2 Implementation of the theories and findings in the model

As in the typical adolescent population, the agents described in the dynamic model are involved in risk behaviors and in conventional behaviors. The level of the involvement varies among the agents. Some of them represent adolescents who are highly involved in risk behaviors. Other agents represent adolescents who are less or not involved in risk behaviors. Furthermore, conventional agents tend to change their behavior less than risk-taking adolescents.

In our model, we assume that on average adolescents who tend to have a high preference for risk behaviors also tend to have a low preference for conventional activities, or stated differently, adolescents who spend a lot of time performing risk behaviors have considerably less opportunity to spend time for conventional behaviors and the other way around. Nevertheless, the simulation can show behavioral profiles that show both: High risk and high conventional behaviors or low risk and low conventional behaviors. The model is thus able to generate atypical profiles of adolescents. These profiles, though atypical, are possible in real life.

In our model, the level of behavioral involvement (e.g., how much an agent smokes or is aggressive) is used to determine the similarity between two agents. The behaviors of the agents change over time. The increase or the decrease of the behaviors depends on the rules of change explained in chapter 3 (see page 45 and 58).

Our model also distinguishes between perceived behavior and real behavior (and consequently also between perceived similarity and real similarity between the agents). We consider this distinction a fundamental characteristic of the agents. Human perception is limited because it is based on limited information and on the persons' interest and attention. This distinction in the model is also related to the change of time and the relative visibility of the properties of the agents. We assume that at the beginning of the interactions, there has been only little time to explore the characteristics of the other agents, in such a way that the initial knowledge of a particular fellow agent is more limited than that knowledge at a later time. This is also a fundamental characteristic of human interactions. In short-term relationships the lack of knowledge of another person, is greater as well as the knowledge of how the other person will react in new circumstances (Jackson, 1993). This knowledge, however, can increase with time.

Not all parameters that define an agent as risky or conventional are explicitly mentioned in the model. For example, we do not have a parameter that defines the level of self-esteem of the agents. However, self-esteem (or other psychological and social variables) is implicitly present in the model in the following way. The model pretends that self esteem is similar in all agents, and therefore we do not need to specify it. This cutting off of some parameters is a deliberate choice we had to make in order to maintain the model as simple as possible. However, we believe that this choice does not interfere with the quality of the model, since this model is mostly focused on explaining dynamics and much less on explaining factors that influence these dynamics; for instance, if self-esteem is a factor associated with the adolescent's tendency to initiate a contact, self-esteem is implicitly incorporated in the model if the model proposes differences in initiation tendency.

2.2 How do adolescents select each other? Selection, preference and mutuality in friendship

2.2.1 Theory

The literature describes several explanatory models of friend selection, including the reciprocity model, the features model and the similarity model (Aboud & Mendelson, 1996). The reciprocity[3] model states that children select others if they like them and if they are liked by them (Aronson & Worchel, 1966). The features model states that people select friends who have certain characteristics (e.g., desirable attributes such as social power or popularity) (Bukowski, Sippola, & Newcomb, 2000; Newcomb, Bukowski, & Pattee, 1993). The similarity model states that children choose friends who have similar characteristics (e.g., level of lifestyle characteristics such as clothing, music, activities) (Bauman & Ennett, 1996; Byrne, 1971; Cohen, 1977; Kandel, 1978). The similarity model has been recognized, by empirical studies and by psychological and sociological literature, to be the prominent model of friendship formation during adolescence (Aboud & Mendelson, 1996; Cohen, 1977; Ennett & Bauman, 1994; Kandel, 1978; Kindermann, 2003). Some empirical researchers on similarity of behaviors and attitudes among friends have discovered that similarity increases over time (Berndt & Keefe, 1995; Kandel, 1978). Other researchers have argued that in established and reciprocal friends the similarity is no longer subject to variation, since stable friends have already the same level of similar behaviors (Bot, Engels, Knibbe, & Meeus, 2005). Thus, it can be argued that the similarity model is more important at the beginning of the friendship than in later stages of the friendship. After the friendships are established other criteria

[3] In the model we use the term "mutuality" to indicate this type of relationship.

may become relevant, such as the ones mentioned by Gottman (1983): Communication clarity, information exchange, the establishment of a common-ground activity, the exploration of similarity and differences, the resolution of conflict, and self-disclosure.

Another relevant question is related to how selection develops in real time. In other words, how does selection unfold in a concrete real-time situation, for example when two adolescents see each other for the first time? In real-time situations adolescents have a lot of opportunities to select new friends, therefore new friendships between adolescents are created on a daily basis during real interactions of the individual with his/her environment. For example, the adolescent, who enters a new school or starts a new sport, has the potential to meet other adolescents and start a relationship with them. Choosing an interaction partner simply means to start a social action directed towards an individual (e.g., adolescent) from one's social environment (e.g., classroom) (Jackson, 1987). If the other individual responds to the first action, an interaction can emerge. If both partners value the interaction positively, the interaction is likely to continue and in the course of time, the friendship among the individuals can emerge.

2.2.2 Implementation of the theories and findings in the model

In our dynamic model, the occurrence of selection is indicated by whether there is interaction or not i.e., by the starting of a network (dyads and/or group of friends) between the agents. Selection can be due to the reciprocal relation between the agents, indicated by the level of reciprocal liking. In other words, the agents, who count as friends, must express a high level of preference for each other. In the model we call this type of friendships mutual interactions and they indicate the presence of *mutuality*. Secondly, selection can be due to similarity in behaviors and attitudes such as substance use or the involvement in sport activities. In this case, the agents have a tendency to initiate an interaction based on the level of the perceived similarity with other agents.

2.3 How do adolescents interact? The characteristics of friendship during adolescence

2.3.1 Theory

Friends are important for the well-being of the individual during the entire life span. However, friendships become crucial during the adolescent years (Hartup, 1983). As children move into adolescence, they spend an increasing amount of time interacting with their friends (Larson & Richards, 1991). On average, adolescents spend approximately one-third of their waking hours with friends (Hartup & Stevens, 1997). Furthermore, 80% to 90% of the adolescents report having mutual friends and several good friends (Hartup & Stevens, 1997).

The structure of the friendship networks is characterized by different levels, namely dyad, clique and crowds. Dyad relationships are considered the most immediate and concrete level of peer interactions. Sometimes, dyad relationships can also include new forms of relationships, mostly romantic and sexual. The dyadic relationships then interlink with each other to form more complex groups of friendship relations, mostly referred to as cliques (i.e., small group of friends). Crowds are clusters of individuals who share the same basic image or identity among peers. Compared to dyads, crowds and cliques are more formal groups, sometimes organized and supervised by adults (e.g., sport association) (Brown & Klute, 2003; Ennett & Bauman, 1994; Hallinan, 1979).

Researchers did not only study the time and the structure of the friends' relationships, but also how friends affect the well being of the individual. Friendship relationships among adolescents are critical for high self-esteem, for accurate understanding of the self and other people (Sullivan, 1953) and for helping adolescents in coping with stressful events (Hartup, 1993). Although friendship has multiple meanings and varies across cultures (Keller, 2004), it has some fundamental dimensions. One of these fundamental dimensions is that friendship is a voluntary rather than obligatory relationship (Bukowski, Newcomb, & Hartup, 1996). Furthermore, contrary to the parents-adolescent relationship, the friends- adolescent relationship is symmetrical (Youniss & Smoller, 1985). In contrast to their parents and other adults, adolescents see their friends as equals. The freedom to choose friends makes friendship a very unique kind of relationship; in the sense that it can become an important platform where an individual can experience and express feelings and behaviors impracticable in hierarchical and asymmetrical types of relationship like the relationships with parents or teachers (Erikson, 1968).

In general, humans have a strong, innate need to belong to lasting, positive and significant interpersonal relationships (Baumeinster & Leary, 1995). However, people do not interact with everybody and do not start a friendship with everybody. With some persons, the interaction is evaluated more positively than with others because the interaction is more pleasurable. Moreover, not all individuals in a social context (such as a classroom in a high school) are equally important and/or noticeable. Some persons are more powerful in the group, therefore are more visible and preferred by others, e.g., popular children, aggressive children (Bukowski, *et al.*, 2000; Steenbeek & van Geert, 2007, 2008; van Geert & Steenbeek, 2005). This preference shows the intentionality or goal-directedness of friendship.

Another important feature of friendship is that it requires mutuality of action, i.e., mutual expression of preference and reciprocity (Brown & Klute, 2003; Bukowski, *et al.*, 1996; Fogel, 1993; Steenbeek & van Geert, 2005, 2007, 2008). This means that only if individuals express a mutual preference for each other, they have developed a friendship. In other words, if an adolescent likes another adolescent, but the reverse is not true, we cannot claim that the two adolescents are friends.

2.3.2 Implementation of the theories and findings in the model

Our model is an interaction model. This means that in our model, the agents have the tendency (i.e., probability) to start an interaction with each other. In the model, interaction is indicated by the frequency (i.e., real occurrence) of the interactions between the agents. The agents do not only interact but they can also assign a value to an interaction, which can be positive or negative. In view of the theoretical principles that guide friendship, our agents choose freely with whom they want to start an interaction. However, in reality adolescents do not always interact freely but sometimes they interact because they have to (for example, because they have to do a compulsory assignment at school together with other students) or because of chance (for example, two individuals are sitting in the bus and start to interact). To resemble this reality, our agents also have the possibility to have random interactions. However, in our model random interactions are not considered a friendship. Friendship, instead, is conceptualized as duration over time of the interaction preference and the resulting actual interaction. Furthermore, only mutual and frequent or lasting interactions are considered as friendship. True friendship is reached only if agents express a mutual preference, i.e., the preference between two persons must be symmetrical, in other words both agents like each other.

As we said earlier, the knowledge about the other agents' properties becomes more visible during the course of time, as a consequence of repeated and increasing exposure to each other (see also section 2.1.2).

2.4 How do adolescents influence each other? Influence and reinforcement

2.4.1 Theory

Researchers have conceptualized peer influence in different ways, which can be grouped under two main definitions. The first one refers to peer influence as "*direct pressure or peer pressure*". This definition describes peer influence as a direct attempt to change, instigate, or prevent specific behaviors. It can also be described as persuasion, in the sense that adolescents are being encouraged or persuaded to change their behavior by peers (Brown, Clasen, & Eicher, 1986; Brown & Klute, 2003; Graham, Marks, & Hansen, 1991). Under this definition we find also more specific but simpler conceptualizations such as the "verbal encouragement by peers to engage or not in certain activities" (Berndt, 1979) and the "frequency of being offered drugs, alcohol or cigarettes" (Kung & Farrell, 2000).

The second definition of peer influence, instead, refers to an *indirect social influence* of peer behaviors. Researchers have shown that indirect social influence (also generally called peer influence) occurs naturally as part of belonging to a particular group (Keefe, 1994) and can emerge through "normative regulation". That is, during interaction with peers the adolescent becomes familiar with the attitudes or behavior patterns of the friendship group (Brown & Theobald, 1999; Brown & Klute, 2003; Graham, *et al.*, 1991). In this view, peer influence refers to "modeling or imitation". In other words, the adolescent adapts his behavior to the behavior of the peers (Akers, 1979; Dunphy, 1963). The conceptualization of peer influence as modeling follows the more general theory of "social learning" (Bandura, 1977). This theory states that individuals can affect other individuals' behavior by setting an example and by providing reinforcement. Dishion, Spracklen, Andrews and Patterson (1996) have applied the concept of reinforcement to peer influence. More recently, Granic and Dishion (2003) have extended the previous work by using a dynamic systems approach. The authors have conceptualized the amount of deviant talk between friends as positive reinforcement. Deviant, or “rule break” talk, was defined as utterances that had antisocial or norm-breaking elements, for example the two adolescents were having conversations about stealing, lying or aggressive acts. Deviant talk is seen as an absorbing state for the antisocial adolescents. By absorbing they mean that deviant talks become a pattern that dyads are repeatedly drawn to, and when the pattern begins, dyads find it difficult to disengage from this topic. In this study, deviant talk is seen as an attractor, i.e., a stable structure that pulls the friendship dyad towards the rigid types of conversation. The authors found that the strength of the deviant talk attractor predicted delinquency and substance abuse three years later. The first key message of the Granic and Dishion’ study (2003) is that in order to understand the mechanisms that underlie peer influence, it is necessary to focus on how these mechanisms unfold over short developmental time scales, for example during a conversation that can take place between two friends. The second key message of the Granic and Dishion’ study (2003) is that, when we are dealing with close relationships as in the case of established friendship pairs, reinforcement is more likely to occur than influence. This is probably due to the fact that when the friendship is already established, the reciprocal friends spend a lot of time together, and thus their behavior may already be very similar and no more subject to mutual influence (Bot, *et al.*, 2005).

Our conceptual framework proposes that the imitation process takes place under the form of two main mechanisms: Influence or reinforcement. In the first case, the current similarity between two adolescents is low, that is, there are many behaviors that they do not have in common. Influence means that an adolescent adopts a new type of behavior (e.g., starts smoking) because a friend is already displaying that behavior. If in the course of time, they become more similar, then we claim that homogeneity is reached through adopting new behaviors from one another, i.e., is reached through influence. In case of reinforcement, the qualitative similarity between two adolescents is high, so the adolescents are very similar in their behavior in that there are many behaviors that they already have in common. In this case, if in the course of time, they become more similar, the change in behavior is due to reinforcement, which we can define as increase or decrease of the frequency of particular behaviors. We believe that what we have defined as influence is not often experienced by the adolescents and has to be considered more an exception than a rule (Alexander, Allen, Crawford, & McCornick, 1999; Arnett, 2007; Denscombe, 2001). We believe that reinforcement is the primary mechanism that makes adolescents change behaviors and increase homogeneity of behaviors with their friends. Our belief is supported by the many researches that have found that during adolescence friends mostly choose each other on the basis of their similarity (Bauman & Ennett, 1996; Cohen, 1977; Ennett & Bauman, 1994; Kandel, 1978; Kindermann, 2003).

Other characteristics of the friendship (e.g., unilateral versus mutual) can play a central role in affecting the strength and the level of the influence. Other empirical evidence pointed out that adolescents without a reciprocal friend are affected more by the friendships they desire than by other group members (Aloise-Young, Graham, & Hansen, 1994; Gaughan, 1999). However, best friends seem to exert a greater influence than the friendship group in general (Urberg, DeĐirmencioĐlu, & Pilgrim, 1997).

In summary, when we consider friendship characteristics, we can conclude that adolescents are more influenced by desired friends than by consolidated best friends, but when they are in a close relationship they can be reinforced more strongly by their best friends than by friends in general. This is so because with the best friend the influence has already occurred and has probably already reached a level of maintenance (or reinforcement) of the similarity. Among best friends the similarity is already maximal, and therefore there can be no further influence but only reinforcement. Reinforcement, instead, can still take place because reinforcement is a slower process than influence. Thus, after a long while of interactions all possible forms of influence, i.e., adoption of behaviors new to the person, have already taken place, whereas the behavioral frequencies related to behaviors are probably still in a process of reciprocally affected change. We can conclude that in established and strongly bonded friendships, reinforcement is more likely to occur than direct or indirect influence.

2.4.2 Implementation of the theories and findings in the model

In our dynamic model, we do not explicitly make a distinction between direct and indirect[4] peer influence, instead we focus on the distinction between influence and reinforcement. Influence refers to a discrete change, more precisely a change that brings an individual from non-involvement to an involvement in a particular behavior (e.g., smoking). For example, for a particular risk behavior, the agent has a beginning level of zero (e.g., he does not smoke). After a number of interactions with another agent, the first agent will have become involved in some risk behavior (for example, he will smoke a few cigarettes). This is an example of influence. Reinforcement, instead, is indicated by a gradual change (continuous change) from some level of involvement to another level of involvement. For example, two agents with qualitatively similar risk profiles, but with different frequencies of performance for each of the risk behaviors, start to interact. If after a number of interactions, both agents end up having the same level (i.e., frequency) of risk behaviors, then reinforcement has occurred. The transitional character of the change (i.e., the absolute difference) determines if influence or reinforcement occurs. A transition from nothing to something, due to the interactions with some other person, is a process of influence; a transition from some level (e.g., low, medium, high) to another level (e.g., from medium to high) due to the interactions with a particular person (who himself has a high level of the property) is called reinforcement.

2.5 Who are the most influential adolescents? Popular adolescents as the source of influence

2.5.1 Theory

Researchers have identified popularity as one of the main explanations of why particular adolescents have strong influences on other adolescents (Mayeux & Cillessen, 2007). In general, popular individuals are by definition more respected and admired by their peers and are, therefore, more

[4] This because the direct influence from A to B is based on the influences that, for example, A has undergone from others (e.g., C,D,E). C,D,E can be other individuals but also mass-media or other types of influence sources.

influential (Latané, 1981). Yet, adolescents who are popular have also the tendency to be involved in risk behaviors. Therefore, popularity is a source of influence on other individuals but also a risk factor for the increase in risk behaviors for the popular adolescents themselves (Allen, Porter, McFarland, Marsh, & McElhaney, 2005). Recent research has found that popular adolescents have also positive features in addition to norm-breaking or risk behaviors, and that the positive features enhance the effects of these behaviors on popularity (Dijkstra, Lindenberg, Verhulst, Ormel, & Veenstra, 2007). For example, popular adolescents have a high level of social competence that makes them able to successfully engage others in the same behavior (Mayeux & Cillessen, 2007).

In order to understand what types of effects popularity may have on other individuals, researchers have made a distinction between socio-metric and perceived popularity. Sociometric status types are typically derived from children's nominations of peers whom they like the most and like the least in their classroom (Coie, Dodge, & Coppotelly, 1982). Perceived popularity, on the other hand, is measured by asking whom they perceive as most and least popular in their classroom. Sociometric and perceived popularity are linked to different behaviors (Cillessen & Mayeux, 2004; LaFontana & Cillessen, 2002). Sociometric popularity is traditionally associated with prosocial behaviors, while perceived popularity is associated with a combination of both positive and negative behaviors (LaFontana & Cillessen, 1998, 2002).

2.5.2 Implementation of the theories and findings in the model

We saw that researchers make a clear distinction between perceived and sociometric popularity. However, in order to make our model less complicated, in the model popularity is a single construct. In our model, popularity is indicated by a high preference for a particular agent by many other agents. Popularity is one of the factors that makes an agent change (i.e., increase or decrease) his behavior towards the profile of another more popular agent, even if the two agents have no similar behavior and there is no reciprocal friendship. In our model popularity, through a positive evaluation of the less popular agent towards the popular agent, leads to influence or reinforcement. In general, popular agents will have a high probability to be involved in risk behaviors and a low probability to be involved in conventional behaviors in comparison with the conventional agents.

2.6 How do adolescents evaluate each other? Evaluation as the motor of change

2.6.1 Theory

Cognitions (such as attitudes, self-efficacy, expectations and intentions) are important aspects of the processes that lead to the onset, maintenance and quitting of risk behaviors, such as smoking (Engels, 1998). Cognitive development during adolescence undergoes major qualitative changes. In early adolescence, formal operational thinking emerges after concrete operational thinking (Inhelder & Piaget, 1958). Therefore, the abilities to process information increase in complexity and sophistication. During this cognitive transformation the adolescents acquire the capacity to think abstractly and to understand symbolic logic (Piaget & Inhelder, 1969). The adolescents are able to generate hypotheses about relations between events and increase their historical perspective (Kaplan, 1991). Changes in cognitive development increase the ability to realize what it means to know something and that to know something is subjective (Rosenblum & Lewis, 2003). Namely, adolescents are able to think about their thinking. The subjective and abstract nature of the adolescents' thinking increases their ability to introspectively evaluate their own thoughts, others' thoughts and what others think about them. In other words, adolescents become more conscious of their own opinions and of the opinions of significant others and become more preoccupied to understand themselves in relation to others (Granic, *et al.*, 2003).

The more sophisticated mind of the adolescent brings new ways to experience emotional events (Crone, 2008; Spear 2000). Researchers have evidence that emotions and cognitive appraisals are strongly related by a bidirectional loop, such that emotions facilitate cognitive appraisals that are congruent with them, while cognitions, in turns, elicit emotions that correspond to the content of the cognitive appraisal (Izard, 1977; Lewis, 1995). Emotions are elicited from cognitive evaluations of events relative to an individual's personal goals (Frijda, 1986; Lazarus, 1982). In other words, an individual evaluates a situation in function of his goals (Frijda, 1986; Steenbeek & van Geert, 2007, 2008). Emotions are the immediate evaluations of the value of the situations that prepare for actions (Frijda, 1986; Steenbeek & van Geert, 2007) and are a socially transparent signal of one's own or an interaction partner's evaluation of the situation (Steenbeek & van Geert, 2007). As we already know, in adolescence, next to the parents, friends become very significant others (Hartup, 1983) and the main developmental task of the adolescent years is to become autonomous from the parents and achieve relationships outside the family walls (Erikson, 1968). Thus, we can expect that adolescents spend a lot of effort to like and be liked by their friends and aimed at evaluating their friends positively and be positively evaluated by them. Furthermore, emotions are the immediate evaluations of the value of the situations that prepare for actions (Frijda, 1986; Steenbeek & van Geert, 2007). For example, if a person feels happy to be with his friend, this positive emotion will be translated into an immediate action as laughing, have fun together, smiling, being kind with each other. During an interaction, the dynamics of these actions (laughing, have fun together, smoking and drinking together) are mutually coupled to the dynamics of evaluation (liking the other person, feeling positive emotions as being happy). These behaviors will probably tend to increase the preference, and thus the likelihood of positive emotions if the person is in interaction with the preferred other; this is an example of the kind of loop between preference, emotion, action and preference.

In short, we conceptualize evaluation as an appraisal corresponding to a particular hedonic tone. The hedonic tone of a person's continuous evaluations has a neurological underpinning (Cunningham, Zelazo, Packer, & Van Bavel, 2007) and can take various qualities, experienced by the persons in the form of emotions.

2.6.2 Implementation of the theories and findings in the model

In our model, evaluation is a way in which an agent evaluates another agent positively or negatively. The evaluation is determined by the preference of A for B, the level of popularity of A and B, and the value of the interaction (that depends on the similarity between the agents). In order to evaluate each other, the agents need to interact. If an agent A interacts with another agent B, and positively evaluates that other agent (and the other way around), then interactions between the two agents are likely to increase. However, the model is also able to depict unusual situations, for example two agents have high similarity but do not interact or two agents who have low similarity interact but express a negative evaluation.

The model does not distinguish between different types of emotions (e.g., happy, sad, etc.). What is most relevant is that positive evaluation results always in a change in the agent system, which amounts to either an increase or a decrease of the preference. The increase effect occurs in the case of positive evaluation. In the case of a consolidated friendship, positive evaluations amount to a maintenance of the current high level of preference for the agent who is positively evaluated. Furthermore, evaluation can foster an agent to change his behavior towards the one positively evaluated. But if an agent evaluates another agent negatively, the probability that two agents will interact is reduced. In other words: Less interaction is less chance of positive evaluations and related emotions, with a particular effect on the further decline of the preference.

3. Summary and conclusion

Developmental psychologists have suggested that two goals are central during adolescence: Reaching autonomy from the parents and forming a stable and integrated identity (Erikson, 1968). To reach these goals, the adolescents increase the interactions with their peers and start to experience new behaviors and life styles outside the family context (Jackson, 1993). In fact, adolescents spend a lot of time with their friends (Hartup & Stevens, 1997), with whom they are involved in a lot of leisure activities (Mahoney, 2000) and share and develop similar behaviors and attitudes (Kandel, 1978). If the need to belong to a peer group is essential for the adolescents and friends to engage in a lot of activities together and have fun together, we can suppose that the adolescents feel positive emotions while they are interacting with their friends and are evaluating them and their behaviors positively. As we reported earlier, evidence suggests that the popular adolescents are more admired and respected peers (Latané, 1981). Therefore, we can suppose that adolescents will tend to imitate the behaviors of the popular adolescent peers. Adolescents in general but mostly popular adolescents are often involved in risk behaviors (Mayeux & Cillessen, 2007). Thus, risk behaviors are often imitated by the adolescents.

Our conceptual framework and related model proposes that the imitation process takes place under the form of two main mechanisms: Influence or reinforcement. Influence means that an adolescent adopts a new type of behavior (e.g., starts smoking) because a friend is already displaying that behavior. Reinforcement, instead, takes places if both friends are already involved in some risk behaviors and increase the behaviors due to the interactions with the friend. In order to select each other and become friends, adolescents need to share many similar attitudes and behaviors. When this is not the case, the adolescents can have the desire to be friends with other not similar adolescents (because they admire them, because they are cool or popular, or just because they have fashion objects). Our model stresses the role of evaluation as motor of the change of behaviors. In our view, only if adolescents like other adolescents, they are prone to adopt their behaviors and eventually increase or decrease other behaviors they could have before the friendship. The model also emphasizes a distinction between preference, which is a form of liking another person, and positive evaluation during an interaction which is also a form of liking the other person. In fact the first form, the preference, is an example of the long-term property of liking somebody else, and the positive evaluation during an interaction is an example of the short-term property of liking somebody else. The model shows that these time scales are intimately and reciprocally related. Our model also highlights that in order to explain how the influence process works during real time interactions and how it may change over time it is necessary to first give a precise definition of the different properties involved in the process.

In summary, our theory and main assumption is that development of friendship and homogeneity among friends is a result of the short-term and long-term dynamics of two mechanisms: Selection and behavioral change that can take the form of influence or reinforcement. During the course of time, friendships and homogeneity develop through sequences of interactions between the friends and their reciprocal evaluations. If the friends are similar in their attitude and show positive evaluations towards each other, they are likely to increase their homogeneity and in the course of time end up mutually reinforcing behaviors and attitudes.

CHAPTER 3

A DESCRIPTION OF A MATHEMATICAL MODEL OF FRIENDSHIP INTERACTIONS AND RISK BEHAVIORS DURING ADOLESCENCE

Laura Ballato*
Nils Schuhmacher**

* *Department of Developmental Psychology, University of Groningen, the Netherlands*

***Department of Culture and Development, University of Osnabrück, Germany*

INTRODUCTION

In the previous chapter we presented a conceptual framework of social interactions and risk behaviors during adolescence based on theoretical and empirical findings in the field of influence and selection and on the perspective of complex dynamic systems. In order to form our conceptual framework we tried to define the key dynamical properties of friendships formation and behavioral similarity among adolescents (Step 1). In the present chapter, we will translate the theoretical framework in terms of mathematical equations and we will present the mathematical version of the previously presented theoretical model (Step 2). In the next chapter, the simulations of the friendship interactions and their behaviors will be presented (Step3). In the last chapter, we will compare the results of the model both with the empirical data collected during the first part of the study and with the theoretical expectations (Step 4) (See figure 1.).

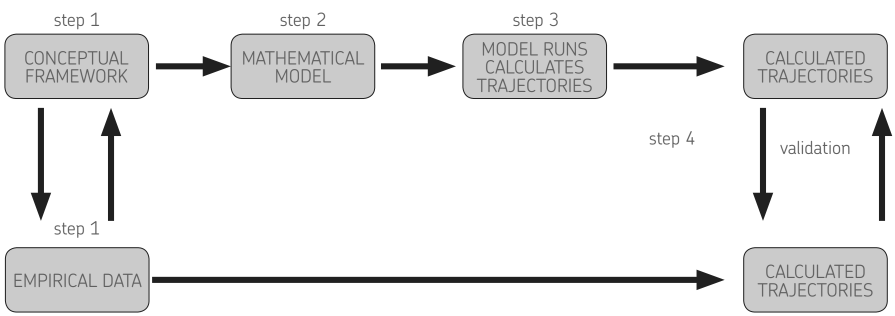

Figure 1. Research steps.

1. The mathematical model

The present model is a combination of a discrete dynamical systems and an agent-based model. Agent-based modeling involves, first, simulation of multiple autonomous agents that interact with each other and with a simulated environment and, second, the observation of emergent patterns from their interactions (Smith & Conrey, 2007; Kalick & Hamilton, 1986). Emergence means that the properties of the system spontaneously emerge in the form of coherent patterns, as a consequence of the dynamics of the system properties themselves (van Geert, 2008). In such a system, each agent typically represents an individual human acting according to a set of theoretically postulated behavioral rules (Smith & Conrey, 2007; Kalick & Hamilton, 1986). The main goal of this technique is to capture key theoretical elements of social and psychological processes (Smith & Conrey, 2007) and observe the empirical trajectories of development they are associated with. The main goal of our model is, therefore, to describe and predict the change of friendship interactions and behaviors based on a dynamic model of agent interactions.

The simulation model consists of 20 individual agents (also known as people, actors or members). We chose to have 20 agents because this number is approximately near to an average school classroom size. The agents are a simplification of real adolescents. They have properties, such as actions (choosing friends, interacting with them, evaluating them etc.). The agents' actions are driven by action rules that are updated at every step of a model run. The action rule determines for each step in the model run whether a particular action will be performed or not. The model also postulates individual differences. In addition to the action repertoire every agent has three properties: A particular type of behavior (i.e., risky and/or conventional); he[1] has personal preferences towards other agents and he has a personality factor, more precisely popularity, by means of which he can influence other agents.

Furthermore, agents, as well as real adolescents, need a social environment to live in and to interact with. Our agents are operating within a classroom of a secondary high school. The agents do not only act in the environment and thus constantly co-create their environment, but they also perceive their environment, although this perception has its limitations. For example, they can perceive some actions of other agents (e.g., choosing friends) and are able to recognize who is the most popular in the classroom. However, the agents do not directly perceive the interactions that other agents may have in the classroom. In our model, the agents perceive the interaction history of other agents by perceiving the popularity of the other agents. The most important property of the agents is their ability to evaluate the interaction with other agents (either positively or negatively) and decide on the basis of this evaluation how to change their own behavior.

In the next sections (1.1 and 1.2), we will present an overview of the agents' properties and rules.

1.1 Overview of the short- and long-term properties of the agents

Before going into the details of the agents' properties, we should define the time frame in which our agents live, in other words the time frame in which the model runs. The developmental time in which our agents live is a simulated school year. A school year is approximated with 200 days. Ten simulation steps shall represent a school day, 50 simulation steps represent a school week and 200 steps describe a month at school. For the agents, therefore, it is possible to have a maximum number of 10 significant interactions with another agent during a school day, thus a total possible maximum of $10 \times 20 = 200$ (simulation steps per day × number of agents) interactions per school day. We chose 10 as a number that represents a school day because we think that on average there

[1] For convenience we will refer to the agents as males; however the model does not specify the gender of the agents.

are about 10 meaningful interactions among pupils per school day. We believe that as long as the number of interactions chosen for the model is within reasonable limits, the exact number does not really matter. We also assumed that the simulation started at the beginning of the school year and that the class is newly formed; the agents have never met before. The time frame in which the model runs is similar to the one described in the real data (see chapter 5).

The starting point of our model is the distinction between short- and long-term properties that characterize our agents.

1.1.1 The short-term properties

Our 20 agents are characterized by ten short-term properties and two main long-term properties (described in the next section). The short-term properties characterize the real time interactions among the agents, thus what happens when agents "meet" for the first time and start to interact with each other in the class. The short-term properties are: *Behavior, perceived behavior, similarity, perceived similarity, preference, popularity, mutuality, interaction, interaction value, and evaluation* (see figure 2). The agents are characterized by two types of *behaviors* which consist of three different types of conventional behaviors (i.e., attitude towards school, work involvement and engagement in sport activities) and by three types of risk behaviors (i.e., use of alcohol, display of aggressiveness and use of soft drugs). The proportional distribution of these properties determines if the agents have a risky, conventional or average lifestyle. The property *similarity* is inferred on the basis of the property behavior and it indicates the level of similar behaviors among the agents (i.e., the extent to which two agents have the same type of behavior).

The perception of the behaviors and the similarity of the agents towards other agents' behaviors changes in the course of time. Therefore, we made a distinction between behavior and *perceived behavior* and similarity and *perceived similarity*. We made this distinction on the basis of the theoretical idea that an agent needs time to know the behaviors of (and the similarity of) others. The first day of an interaction, an agent has not yet got the time to know all the properties of other agents. At the beginning, the perception is a subjective perception, or more precisely a guess, and therefore it can be inaccurate. For example, at the beginning of their interaction history, an agent may perceive another agent more risky than he is in reality. With time the knowledge of the behaviors of others increases and becomes more realistic. The distinction of behavior and perceived behavior (and similarity and the perceived similarity) is related to the theoretical idea that psychological phenomena, e.g., the knowledge that someone has of somebody else, are not static but change and transform themselves over the course of time (van Geert, 1994; 2003).

The agents do not only have behaviors but they also pursue actions towards other agents. One of these actions is to *interact* with each other. In model terms, an interaction is described as the action directed towards another agent. The model calculates the decision to make two agents interact on the basis of a random function of *mutuality*. Mutuality is related to preference. Therefore, the more two agents like each other; the more probable is an interaction. However, expressing a *preference* towards another agent does not mean to be friends. Only when both agents express a high preference toward each other, they are considered as friends. The agents express also a value of the interaction (*interaction value*), that can be positive or negative based on the level of similarity (the higher the similarity the higher the probability to have a positive interaction). Another action property of the agents is their *evaluation* of each other. An agent can evaluate another agent positively or negatively. A positive evaluation results always in an action that leads to an increase in preference level based on a positive evaluation. Furthermore, evaluation can foster an agent to change his behavior towards the one positively evaluated, i.e., to imitate the frequency of the behavior of the other person who was evaluated positively. But if an agent evaluates another agent negatively, the probability that two agents will interact is reduced.

The last characteristic of the agents is the level of their *popularity*. Some of our agents are more popular than others. Popularity is inferred from preference, since it is the result of the preference of all agents for a particular other agent that determines the level of that agent's popularity. The agents use preference as a shortcut for the agent's perception of the frequency of interactions between agents, which is based on the preference of those agents for the agents with whom they interact. An agent evaluates another agent positively if the other agent is popular.

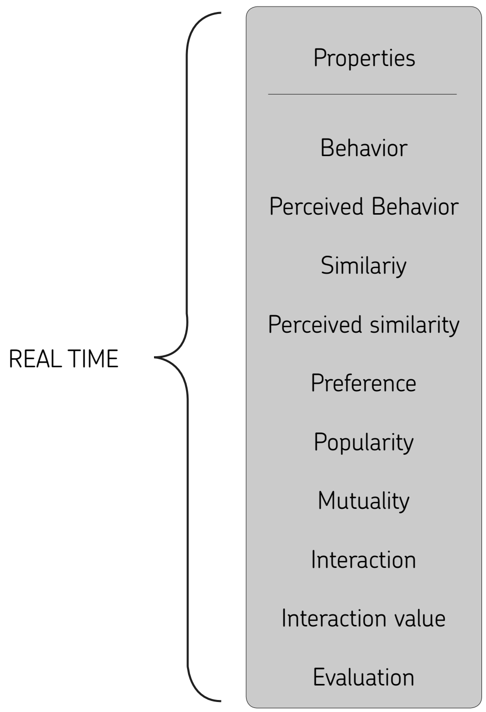

Figure 2. Overview of the short-term properties of the agents.

1.1.2 The long-term properties

As stated before, an interaction of an agent with another agent is considered as a short-term property. However, as for real adolescents, you would not call a single interaction of two agents a friendship because friendship implies long-term interactions. Friendship needs time to develop and to form into a stable pattern of interaction. Friendship is, therefore, described in our model as a long-term property. The long-term properties represent stable properties that imply a certain level of stable order and structure, they need time to emerge and express the developmental outcomes of the short-term properties.

Our ten short-term properties interact over time to produce two main long-term properties: *Friendship and homogeneity in behaviors*. Friendship and homogeneity in behaviors are constructed as a consequence of the dynamics of the ten short-terms properties. More precisely, the self organizing properties are the results of the iterative application of the dynamic rules and emerge from the non-linear interactions among the components of the system. The two main long-term properties can be seen as complex patterns that the system tries to maintain. These stable patterns that spontaneously emerge are known as "attractor' states" (however, an attractor state can also consist of a cycle of states or a pattern of states). An attractor is a state towards which the system is automatically drawn, given a broad range of starting points and conditions (e.g., preference for another agent, similarity in behaviors) (Steenbeek & van Geert, 2005; see also chapter 2, page 22). Although friendship and homogeneity in behaviors are the most common outcomes of the model, they are not the only possible ones. For example, friendship can also dissolve after the course of time. But the agents could also decrease their homogeneity instead of increase it.

In summary, the model outcomes consist of the whole variety of formation to the dissolution of friendship and from increase or decrease in homogeneity. The model is in principle able to generate more outcomes; however we were not interested in studying all the possible outcomes but instead we focused on the ones relevant to the theories and the findings. Therefore, in this chapter, we will mainly focus on the two main outcomes: Homogeneity and friendship.

1.2 Overview of the agents' rules

In the previous section, we described the short- and long-term properties that compose our model. However, we still have not explicitly described how the long-term properties emerge through the interplay of the short-term properties. In other words: What are the mechanisms that make these properties change over time? As we said earlier, our rules of change are based on theoretical findings and empirical researches. More precisely, in order to create our rules we followed the hypotheses of Bauman & Ennett (1996), Cohen (1977), and Kandel (1978). We summarized the hypotheses of these authors under the form of one single hypothesis which states that adolescents select their friends among those persons who have similar characteristics and that they socialize one another in a manner that increases this similarity. Our contribution goes further since we also extend the previous hypothesis by incorporating other theories (e.g., about popularity) and by expressing them in the form of dynamical rules. In short, our contribution consists of the following summary and interpretation of various theories and empirical findings. The first rule states that increase of friendship depends on the behavioral profile (similarity), preference and/or popularity (with the first case, similarity, being more probable) of the participants. The second rule states: When selection occurs and the interactions between the adolescents start, they will co-adapt their behavioral profile so that, under conditions of repeated positive evaluations, their behavioral profiles become increasingly homogenous. The third rule states: When two adolescents significantly have repeated negative evaluations (i.e., they do not have fun together, they do not like each other) their interactions are likely to become shorter and then dissolve, their behavioral profile will remain the same or become dissimilar. The positive evaluation (i.e., laughing, being happy) by an agent of a particular other agent increases as a function of popularity of the evaluated person. The fourth rule states that the resulting magnitude of change in the other agent is moderated by the evaluation of the agents that depends, among other factors, also on the level of popularity of the adolescents involved in the interaction. The fifth rules states that to choose a friend is a free act. In other words, agents choose their friends freely only on the basis of their mutual preferences and they are not constrained by external factors, such as parents or teachers. The theoretical rules have been translated into mathematical equations, which will be described in section 1.5.

1.3 General features of the model

The present model is a combination of a discrete dynamical systems and an agent based model. The formal model consists of a number of coupled equations and decision rules that work in an iterative way. The model is implemented in the form of a Visual Basic (VB) for applications model and runs in Microsoft Excel. We started with a pilot research, in which the model consisted of the simplest possible combination of agents, described by means of two matrices. A matrix is a description of the value of a particular property assigned to each agent at a particular time. We started this simple model in the form of an Excel spreadsheet, because Excel is easy to use and is available on almost any computer. This simple version of the model has been further developed into the most recent version that is ultimately composed of 20 agents and ten matrices. To improve the visualization of the model results the VisualBots plugin has been installed. VisualBots is an ActiveX Control for Microsoft Excel for personal use and is a free of charge. It is an agent based simulator that allows to design and simulate multiagent worlds, e.g., on grid cells (Waite, 2006).

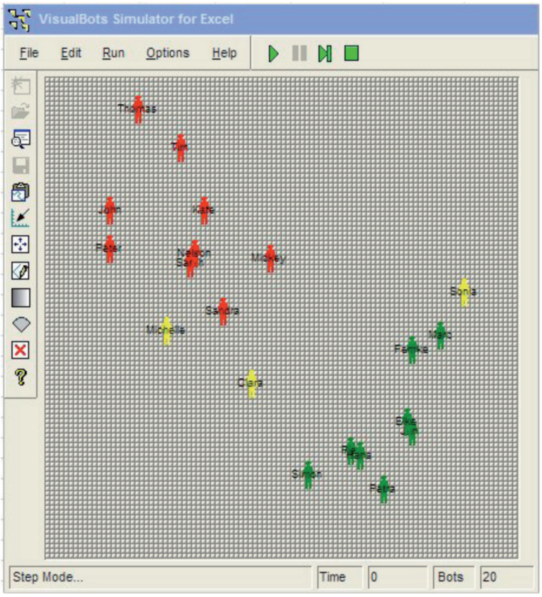

Figure 3. Step 0 of the simulation (t=0).

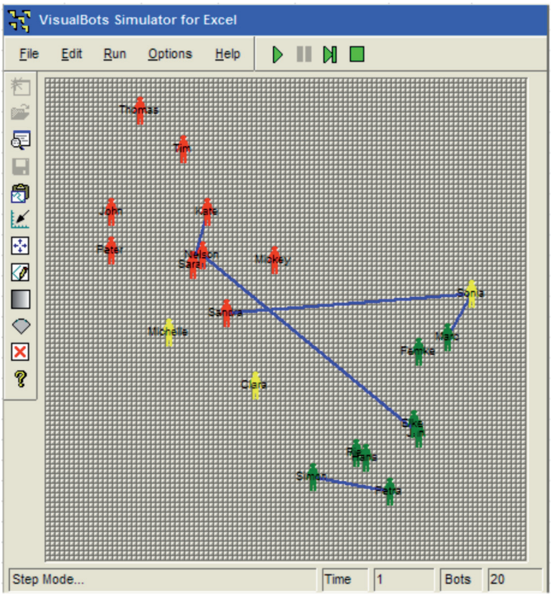

Figure 4. Step 1 of the simulation (t=1).

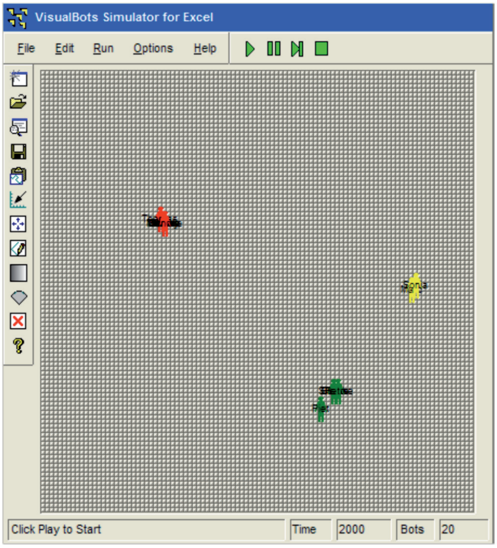

Figure 5. Step 2000 of the simulation (t=2000).

Figure 3, 4 and 5 show an example of a simulation of VisualBots over time. The figures show the agents on the behavioral state space with the x axis indicating conventional behaviors and the y axis indicating risk behaviors. Figure 3 shows the beginning of the simulation. At this stage, the network is not yet composed, the agents are still separated (that is, they do not know each other). The colors indicate the type of behaviors: The red agents are the risky agents, while the green are the conventional ones. In other words, the green ones have a majority of conventional behaviors, with a minority to zero risky behaviors, while the red ones have a majority of risk behaviors, with a minority to zero conventional behaviors. The yellow are average agents. In figure 4 you can see the starting of the formation of the network (i.e., start of the simulation t1). The agents attract each other on the basis of the rules we have given them. As you can see from figure 4, there is a mutual preference between the risky and the conventional agents, i.e., risky agents prefer risky agents and conventional the conventional agents. Figure 5 shows the end of the simulation. As you can see, three friendship clusters appear each of one is composed by agents with the same colors.

A basic idea of the model is that you can describe its properties by means of a set of matrices. Therefore, each of the previous properties has been translated into an Excel matrix. The matrices are time-indexed (i.e., there is a matrix at t1, t+ Δt, t+ 2Δt, t+ 3Δt etc.) and are characterized by an iterative process. The iterative process implies that all matrices are updated at each model step, in order to model the growth of friendships relationships and the increase or the decrease of behaviors. Updating means that the values of the properties are newly calculated at each time step.

This iterative process of updating yields a series of successive state values (i.e., X_3 is calculated from X_2; X_4 from X_3 and so forth). The succession of the time-indexed matrices is the way to display a process of change over time of the property described in the matrix at issue. The underlying model is also a stochastic model. This means that it is influenced by random processes (Krengel, 2005). In a random process, there is a certain level of indeterminacy in its future evolution. This indeterminacy is described by a probability distribution. Each step in the model is partly determined by a value drawn from a particular probability distribution.

As we previously said, the matrices are composed of the 20 agents. To distinguish the agents, we gave them a name (i.e., Tim, Kate, Marc, Sarah etc). Agents have names and a value on a specific property (e.g., Marc: preference for Sarah = 0.94). The range values can vary among the properties. Some properties have a range between -1 (minimum) and +1 (maximum), others between 0 (minimum) and 1 (maximum). The most relevant aspect is that the range of all the properties is continuous. This means that all values within the range are possible (e.g., 0.9; 0.8; 0.7 etc). Another important aspect is that the numbers displayed do not aim to represent a true score or an estimated score on some sort of psychological test. The values represent a behavioral index, in other words a model-specific evaluation of a number that determines the strength of a property or variable and gives an estimation of how much a property is important for the agents. Furthermore, we had to define when and how a score can be considered high or low. We did this by using the average values among the agents as threshold: A score that falls above the average threshold is considered high; instead a score that falls below the average values is low.

In the following section, we will explain in detail each of the properties by describing their theoretical meaning, their function and the relation with the other properties. Each of the properties is illustrated by a simple graphical representation of the corresponding matrices at time t. The example matrices are composed of four agents: Tim, Kate, Marc and Sarah and their relative scores on each of the properties at time t. Note that the real matrices are much more complicated. They are composed of 20 agents and change over time. For a complete description of the matrices and the model, see www.paulvangeert.nl

1.4 Description of the agents' properties

1.4.1 Behavior and perceived behavior

The property "behavior" is a list of behaviors used to specify an agent's behavioral and habit profile. It consists of both conventional and risky behaviors. Matrix 1 specifies three examples of conventional behaviors (study, doing sports, work) and of risk behaviors (use of alcohol, aggressive behavior and use of soft drugs). The behavioral matrix is used to determine the similarity between two agents. The numbers mean, for instance, importance of the behavior or degree of involvement of the behavior of the person in question. Zero means that there is no importance and thus no degree of involvement. One means maximal possible level of importance and the maximum possible level of involvement, which depends on the behavior in question and on what one could define as maximal involvement for the age range in question.

AGENTS	STUDY	SPORTS	WORK	SUM	ALCHOHL	AGGRES.	SOFT DRUGS	SUM
Tim	0.54	0.74	0.78	*2.06*	0.03	0.10	0.24	*0.37*
Kate	0.69	0.76	0.49	*1.94*	0.15	0.25	0.06	*0.46*
Marc	0.25	0.31	0.25	*0.81*	0.63	0.78	0.74	*2.15*
Sarah	0.34	0.29	0.48	*1.11*	0.90	0.81	0.48	*2.19*

Matrix 1. Behavioral matrix at t of 4 agents

Matrix 1 represents the behavioral matrix of 4 agents at the t. The matrix at t+1 will be slightly different, due to the updating procedure. As we can see in the matrix, Tim and Kate represent two adolescents who have a relatively higher involvement in conventional behaviors (sum conventional behaviors of Tim = 2.06; Kate = 1.94) than in risk behaviors compared to Marc and Sarah (sum conventional behaviors Marc = 0.81; Sarah = 1.11). On the contrary, Marc and Sarah represent two adolescents who have a relatively higher involvement in risk behaviors (sum risk behaviors of Marc = 2.15; Sarah = 2.19) than in conventional behaviors compared to Tim and Kate (sum risk behaviors of Tim = 0.37; Kate = 0.46). Following the model rules we can expect that, due to the fact that Tim and Kate are similar (and Marc and Sarah), in the course of time they have a high probability to develop a strong preference for each other, to interact more frequently, and to evaluate each other positively. Probably, at the end of the school year, the dyad Tim and Kate and the dyad Marc and Sarah will have developed a stable form of friendships. Furthermore, their behavioral profiles will be more homogenous than at the beginning of the school year. This example illustrates how our model simulates ‘real’ adolescents, who the due to their common interests, become friends and influence each other by increasing the behaviors that both like.

The perceived behavior

As already mentioned every agent has a subjective perception of all the other agents’ behaviors. This subjective perception is called the perceived behavior. The theoretical idea of this assumption is, that over the course of time the agents in a class communicate and interact with each other and get to know more and more about the real behavioral profile of the classmates. The behavior that an agent perceives from another agent is calculated on the basis of a distortion of the first agent’s real behavior. Theoretically, the idea of distortion comes from the idea that you need time to know the properties of someone else, and that at first you start with a very vague, i.e., distorted, image of the properties of the other person. In the model, this distortion is initially randomly chosen and decreases over the course of time. To simplify the illustration of this example we assume that Tim perceives Kate’s behavior with a distortion of 0.01 for conventional behaviors and -0.01 for risk behaviors. This means that he perceives Kate a little bit more conventional and less risky that she actually is. On the other hand he has a distortion of 0.05 for risk behaviors and -0.05 for conventional behaviors in the perception of Marc and Sarah. This means that he perceives Marc and Sarah more risky and less conventional than they indeed are.

By way of example we want to calculate how Tim perceives Kate's study behavior. Kate's true study behavior is 0.69. Tim and Kate have a distortion value of 0.01. Let us assume we are in simulation step t = 200. The longer the model is running, the smaller the distortion will be. With α (alpha can be used to speed up or slow down the process of recognizing the real behavior of another agent) we can calculate now the perceived study behavior of Tim for Kate:

$$PerceivedBehvior_t^{AgentA,\, AgentB} = TrueBehvior_t^{AgentB} + e^{-\alpha \cdot t} \text{x} distortion$$

$$PerceivedBehvior_{200}^{Tim,\, Kate} = 0.69_t + e^{-0{,}001 \cdot 200} \text{x} 0.01 \approx 0.69 + 0.008 = 0.698$$

We can conclude that Tim perceives that Kate is a better student than she actually is (0.698 compared to 0.69) (Matrix 2).

Tim perception of

AGENTS	STUDY	SPORTS	WORK	ALCHOHL	AGGRESSIV.	SOFT DRUGS
Kate	0.698	0.768	0.498	0.142	0.242	0.052
Marc	-0.160	-0.100	-0.160	1.040	1.190	1.150
Sarah	-0.069	-0.119	0.071	1.310	1.220	0.889

Matrix 2. Perceived Behavioral matrix at t of 1 agent

1.4.2 Similarity and perceived similarity

The property "similarity" indicates the level of similar behaviors among the agents. The similarity matrix is a symmetrical matrix that calculates the relative distance between two persons (i.e., distance divided by the number of behavioral categories) and takes the average of the overall behavior matrix as value. For example, Tim has a conventional profile of 2.06 and Marc has conventional profile of 0.81; Tim has a risk profile of 0.37; and Marc has a risk profile of 2.15. We can then calculate the dissimilarity profiles of both agents:

- *Average conventional profile Tim and Marc* = ABS ((0.54 +0.74 + 0.78) – (0.25 + 0.31+0.25)) / 3 = 0.42 (dissimilarity)
- *Average risk profile Tim and Marc* = ABS ((0.03 + 0.010 + 0.24) – (0.63 + 0.78+0,74)) / 3 = 0.59 (dissimilarity)

The greater the dissimilarity values, the greater the dissimilarity between the two agents.
In order to calculate the similarity it is necessary to subtract the averages of the dissimilarity values from 1 that is: S = 1 -(0.42 + (0,59)/2)) = 0.49 similarity value. The higher the similarity value, the more similar the two persons are (Matrix 3).

AGENTS	Tim	Kate	Marc	Sarah
Tim				
Kate	*0.97*			
Marc	0.49	0.53		
Sarah	0.54	0.57	0.65	

Matrix 3. Similarity matrix at time t of 4 agents

As we can see from matrix 3, Tim and Kate represent two adolescents that at time t have a higher similarity for each other (similarity Tim/Kate = 0.97) than, for example, Sarah and Tim (similarity Sarah/Tim = 0.54). This means that Tim and Kate are involved in the same type of behaviors. Recall that Tim and Kate were high in conventional behaviors (see Matrix 1). Thus, Tim and Kate like to study, to do sports, and prefer to work rather than smoking, drinking or displaying aggressiveness. On the contrary, Marc and Sarah are similar (similarity Marc/Sarah = 0.65). They are both high in risk behaviors (see matrix 1); this means that they like more smoking, drinking and display aggressiveness than studying, doing sport or working.

The perceived similarity

Since agents have a subjective impression of the other agents' behaviors and since the similarity is a property inferred from behavior, the agents have also a subjective impression of the similarity. An agent feels similar to another agent on the basis of what he thinks is the other agent's behavior (see also section 1.5). However, this similarity at the beginning is only based on a perception, while with time it becomes more realistic. The perceived similarity is calculated as follow:

$$PerceivedSimilarity_t^{ij} \quad = \quad 1 - \sum_{k=1}^{n} \left| Behavior_t^{k,i} - PerceivedBehaviour_t^{k,ij} \right| \Big/ n$$

With n = number of behaviors, k is the index for the behavior, and i and j are index letters for two agents. For example we want to calculate the similarity that Tim perceives between himself and Kate (for Tim's true behavior see Matrix 1; for the behavior that Tim perceives of Kate see Matrix 2). The number of behaviors is 6 (n = 6). We calculate the perceived similarity as follow:

$$PerceivedSimilarity^{Tim,Kate} =$$
$$1 - \frac{[ABS(Tim^{Study} - PerceivedBehavior^{Study,TimKate}) + \ldots + ABS(Tim^{Drugs} - PerceivedBehaviour^{Drugs,TimKate})]}{6}$$
$$= 1 - \frac{[ABS(0.54 - 0.698) + \ldots + ABS(Tim^{Drugs} - PerceivedBehavior^{Drugs,TimKate})]}{6}$$
$$= 1 - \frac{[0.158 + \ldots + ABS(Tim^{Drugs} - PerceivedBehavior^{Drugs,TimKate})]}{6}$$
$$= 1 - \ldots$$

The following matrix (Matrix 4) shows the perceived similarity of agent Tim towards three other agents.

	Kate	Marc	Sarah
Perceived similarity of Tim versus	1.35	1.09	1.15

Matrix 4. Perceived Similarity matrix at time t of 1 agent

1.4.3 Preference

The property "preference" indicates how much an agent likes another one. As you can see from the example matrix displayed below (Matrix 5), if the preference of Tim for Kate is high (0.85) and the preference of Kate for Tim is high (0.85), then Tim and Kate have high preference for each other. If the preference of Kate for Sarah is high (0.55) but the preference of Sarah for Kate is lower (0.52), then the preference is asymmetric, which might occur if Sarah for instance is a popular girl. The preference matrix is an asymmetrical matrix, for instance Kate has a higher preference for Sarah than Sarah has for Kate. The column total specifies how much the other agents like another agent. The matrix should be read in such a way that the agents on the vertical axis at a preference for the agents on the horizontal axis; self-preference does not exist (black rectangle).

From the basic property preferences, two other properties are inferred: popularity (1.4.4) and mutuality (1.4.5).

AGENTS	Tim	Kate	Marc	Sarah
Tim		0.85	0.49	0.54
Kate	0.85		0.53	0.55
Marc	0.44	0.48		0.94
Sarah	0.49	0.52	0.94	
Total	*1.78*	*1.86*	*1.95*	*2.03*

Matrix 5. Preference matrix at time t of 4 agents

1.4.4 Popularity

The property "popularity" is the result of the preference of all the agents for another agent (see column total of the previous matrix). Popularity is calculated by summing the preferences of the agents for another agent (e.g., popularity of Sarah is calculated by summing 0.54 (preference of Tim for Sarah +0.55 (preference of Kate for Sarah) + 0.94 (preference of Marc for Sarah = 2.03). Popularity is considered as a sum of the preference. The agents express a real preference for the other agents; thus, the model employs a socio-metric notion of popularity and not a perceived popularity (see page 35 of chapter 2 for the theoretical distinction). From the basic property preferences, two other properties are inferred: popularity (1.4.4) and mutuality (1.4.5).

AGENTS	Popularity of
Tim	1.78
Kate	1.86
Marc	1.95
Sarah	2.03

Matrix 6. Popularity matrix at time t of 4 agents

1.4.5 Mutuality

The property "mutuality" is indicated by a combination of the preferences of two agents for each other. This property is used to determine the existence of a friendship pair, taken as minimum value of the preference. For example, if Kate likes Sarah with a preference of 0.55 and Sarah likes Kate with a preference of 0.52 (see Matrix 5), the mutuality can be no bigger than the smallest of the two preferences. Therefore, in the example below (Matrix 7) the mutuality level of Sarah and Kate is equal to 0.52. This matrix is a symmetrical matrix; this allows the presence of only one number to indicate the friendship. We assume that two agents are friends if their mutuality is above the average of the mutuality scores of all agents. In this example the average mutuality is 0.62. Therefore, Sarah and Kate are not considered as friends. Only the dyad Kate and Tim (mutuality = 0.85) and the dyad Marc and Sarah (mutuality = 0.94) are friendship dyads.

AGENTS	Tim	Kate	Marc	Sarah
Tim				
Kate	0.85			
Marc	0.44	0.48		
Sarah	0.49	0.52	0.94	

Matrix 7. Mutuality matrix at time t of 4 agents

1.4.6 Interaction

The property "interaction" is composed of two different matrices: Interaction frequency (matrix 8) and interaction value (Matrix 9). The first indicates if two agents interact and the second indicates the value (positive or negative) assigned to the interaction by the interacting agents (e.g., they like it or not).

The *interaction frequency matrix* is a matrix that describes whether two agents interact at time t, and takes values 1 (they interact) or 0 (they don't interact). The matrix is determined on the basis of a random function of mutuality, that is the higher the mutuality, the higher the probability to interact, i.e., if we both like each other, we are likely to look for each other's company and thus to introduce an interaction.

We set two constraints for calculating the probability of interacting: The maximum value is 0.9 and the minimum value 0.1. We choose 0.9 otherwise two agents would always interact, if their mutuality is 1, even if the interaction is a random function of the mutuality. In other words, all random numbers drawn from the 0-1 interval will be smaller than 1, and thus the two agents will always interact, which is unrealistic. These limits express the fact that interactions are not completely determined by the persons' own choice and initiatives. They are also determined by force, circumstance, accidental factors etc. For example, in real life adolescents also interact with adolescents with whom they have low mutuality. Take for example two adolescents who are in the same class but they are not friends. Even if they are not friends, they can still have interactions: For example because the teacher assigns them to a task that needs to be done together. On the other hand, adolescents who are close friends do not always interact, for example because they can also be friends with other agents or because they are sometimes not present in the same time in the class.

AGENTS	Tim	Kate	Marc	Sarah
Tim				
Kate	1			
Marc	1	0		
Sarah	0	1	0	

Matrix 8. Interaction (frequency) matrix at time t of 4 agents

The *interaction value matrix* is a random function of the similarity and the interaction matrix. The value of the interaction is a random number chosen from a normal distribution, the mean of the distribution depends on the similarity. If the similarity is above the similarity threshold (the similarity threshold is the average of all the values) we chose a positive mean between 0 and 1 depending on the value (amount) of similarity; if the similarity is below the similarity threshold we chose a negative mean between 0 and -1 depending on the value (amount) of similarity. The standard deviation is within a range of 0.0 and 0.4 set to 0.3.

For example: Tim and Kate had an interaction (Matrix 8). Their true similarity is 0.97 (see Matrix 3). This similarity value is normalized depending on the similarity threshold[2]. The average is set to this nor-

[2] The similarity threshold ϴS is used to normalize the similarity values. If the similarity value is below the threshold, the normalized similarity becomes negative, else it becomes positive. If we receive a normalized similarity value bigger than 1, it is set to 1. If the normalized similarity value is below 1, it is set to -1.Therefore we achieve μ€ [- 1,1] . ϵ(this parameter is an element of… (the parameter lies between 1 and -1). Furthermore, if the randomly drawn interaction value is bigger than 1, then the interaction value is set to 1 and if it is smaller than -1, then the interaction value is set to -1, so the interaction value lies between -1 and 1.

malized similarity value, let say in our case this value is set to 0,62 (it is positive, because Tim and Kate are quite similar, in other words: Their similarity is higher than the threshold). The average similarity is calculated as follows:

Average similarity = (0.97 + 0.49 + 0.54 + 0.53 + 0.57 + 0.65) / 6 = 0.62.

Following the example of Matrix 3 of Tim and Kate the calculation for the normalized similarity value is: (0.97 - 0.62) / (1 - 0.62) = 0.92 (average similarity-threshold/1-threshold). The standard deviation is set to 0.3. Then the computer model generates a random number from a normal distribution with *SD* = 0.3 and *M* = 0.92 which can result in the interaction value of 0.39.

AGENTS	Tim	Kate	Marc	Sarah
Tim				
Kate	0.39			
Marc	-0.55	0.00		
Sarah	0.00	-0.16	0.00	

Note. These values are calculated on the basis of a random function, therefore can never truly correspond to ones of the similarity matrix.

Matrix 9. Interaction (value) matrix at time t of 4 agents.

The fact that the value of the interaction matrix is a random function of the similarity (the higher the similarity, the higher the probability to value our interaction positively) gives the agents the possibility of having a high similarity but do not always interact with a positive interaction value. For example, in Matrix 3 we noticed that Marc and Kate were similar (similarity= 0,97). In Matrix 8, we see that they interact (interaction frequency = 1) and in Matrix 9 we see that they have a positive interaction (interaction value is = 0,39). However, since Marc and Tim are less similar (similarity = 0,49), if they interact (interaction frequency =1), they express a negative value of the interaction (interaction value=-0,55). In other words, Marc and Tim are interacting but they do not enjoy this interaction so much as Kate and Tim do. Furthermore, we see that Marc and Sarah in spite of their high similarity (similarity = 0,65) and strong friendship (mutuality 0,94), at this point in time do not interact (interaction frequency=0) and therefore they do not express a value for this interaction (interaction value=0).

1.4.7 Evaluation

The property evaluation is a function of four properties: The presence or absence of an interaction between two agents, the popularity of an agent, the value of the interaction between two agents, and the preference value between two agents.

The evaluation should not be confused with the interaction value. The interaction value is the evaluation of the action, while the evaluation is the evaluation of the agent after the action. The interaction value is only one component that determines the evaluation of the agent after the action, but is of course not the evaluation itself. The interaction value and the evaluation are composed of different properties and are calculated and updated by different rules (see next section). The interaction value is a short-term property, which can vary from interaction to interaction, because it is quite strongly determined by a stochastic element. Whereas, the evaluation of a particular agent for other agents is a short-term property, which changes only very little as a consequence of a single interaction, but can vary quite dramatically as a consequence of a long series of interactions.

The following figure displays the evaluation of the 4 agents for each other after an interaction. For example, we now know that Tim and Kate are good friends (Matrix 7), have similar behavior (Matrix 3), and during the interaction expressed a positive value (Matrix 9). Therefore, Kate expresses also a positive evaluation towards Tim (0.29) and Tim towards Kate (0.31) (Matrix 10). Contrary, Marc and Tim are not good friends (Matrix 7), they have dissimilar behaviors (Matrix 3), and their interaction is negative (Matrix 9). Therefore, Marc evaluates Tim negatively (- 0.36) and Tim evaluates Marc also negatively (- 0.32) (Matrix 10).

AGENTS	Tim	Kate	Marc	Sarah
Tim	0.00	0.31	-0.32	0.00
Kate	0.29	0.00	0.00	-0.51
Marc	-0.36	0.00	0.00	0.00
Sarah	0.00	-0.16	0.00	0.00

Note. These values are calculated on the basis of a random function, therefore can never truly correspond to the ones of the previous matrices.

Matrix 10. Evaluation matrix at time t of 4 agents

Summarizing, Kate and Tim like each other and evaluate each other positively, while Marc and Tim do not like each other and evaluate each other negatively. This means that between Kate and Tim there is a high probability that a behavior will evoke positive emotions and this can result in a change in their behavior (for a description of the rule, see next section). This example combines a positive evaluation with being good friends and negative evaluation with not being friends, whereas it is of course possible in the model to have a negative evaluation even among good friends; however among good friends negative evaluations will thus occur considerably less frequently than among people who don't like each other. However, our model does not distinguish between the different types of emotions. Positive evaluations can take different forms (e.g., high positive emotions, like laughing, having fun together, being kind with each other, being happy). What is most relevant is that positive evaluation always results in an action, that results in increase in preference level for the agent who is positively evaluated. Furthermore, evaluation can foster an agent to change his behavior towards the one positively evaluated. But if an agent evaluates another agent negatively, the probability that two agents will interact is reduced. Summarizing, evaluation effects the preference and the behavioral imitation which in turn effect the probability of a later interaction.

1.5 Description of the agents' rules

As we explained earlier, each agent generates behaviors by the use of simple rules, calculated by means of a fixed procedure, while the parameters and states can be updated at each model step. This means that the way of calculating for example the risk behaviors does not change during the simulation. However, the value for the risk behaviors is updated at each model step, in other words it adapts to the currently given situation. The conceptual phrasing of the rule is often based on an "*if-then*" statement but the phrasing of the rule itself takes the form of a *difference equation*, i.e., an equation describing the change in a variable on the basis of the values of other variables.

Before going into the details of the description of the model's rules, we should still remember that the main goals of the agents are to interact with other agents and evaluate them positively. However, the agents' proactive choice of the different behavioral rules is limited. In our model, the reaching of a goal is implemented in the nature of a dynamic systems model: The process is the goal, and the goal is the process. In other words, the goal of forming a stable friendship is not explicitly given. But due to the underlying processes the result of the simulation can be a formation of stable friendship patterns.

1.5.1 Rules of behavior

Conceptual rule

The change at time t +1 of an agent's behavior is proportional to the difference between the agents' behavior and the behavior of an agent with whom he had an interaction; the change represented by the parameter c depends on the evaluation of the interaction.

Mathematical rule

$B^{i}_{t+1} = B^{i}_{t} + (B^{j}_{t} - B^{i}_{t}) \times c$

B^{i}_{t+1} = Behavior of Agent i at time step t+1

B^{j}_{t} = Behavior of Agent j at time step t

c = Change factor (depending on evaluation)

The behavioral matrix is updated at each model step, as a consequence of the evaluation of an agent on another agent's behaviors or habits. Agents tend to copy the behavior of other agents, either through reinforcement or influence, depending on the evaluation of the agent from whom the behaviors are copied. Thus, copying means that the matrix of one agent is updated at each time step; so as to increasingly resemble the matrix of another person, whose behaviors are copied by the first agent.

1.5.2 Rules of perceived behavior

Conceptual rule

The perceived behavior by an agent of another agent's behavioral tendency depends on the real value of that tendency plus a distortion.

Mathematical rule

$B^{k,ji}_{t+1} = B^{k,j}_{t+1} + distorsion^{k,ji}_{t+}$

$B^{k,ji}_{t+1}$ = Perceived Behavior of Agent i for agent j

$B^{k,j}_{t+1}$ = Real behavior of Agent j at time t+1

$distorsion^{k,ji}_{t+}$= Normally distributed random variable

The perceived behavior of Agent i for Agent j for t+1 is calculated on the basis of the true behavior of Agent j at t+1 plus the value of a distortion function. The distortion function delivers a randomly drawn number from a normal distribution with the average depending on the similarity and the standard deviation defined by the modeler.

1.5.3 Rules of similarity

Conceptual rule

The similarity between Agent i and Agent j for t+1 is calculated as a distance function of the behavior of Agent i and Agent j at t+1. The distance is calculated by taking the absolute value of the difference between the behavioral tendencies of agent i and the corresponding behavioral tendency of agent j.

Mathematical rule

$S^{i,j}_{t+1} = dist(B^{i}_{t+1}, B^{j}_{t+1})$

$S^{i,j}_{t+1}$ = Similarity of Agent i and Agent j

$dist(B^{i}_{t+1}, B^{j}_{t+1})$ = distance function of the behavior of agent i and agent j at t+1.

The similarity matrix is updated as a function of the behavior matrix and it is related to the preference and behavior matrices.

1.5.4 Rules of perceived similarity

Conceptual rule

The perceived similarity by an Agent i of an Agent j equals one minus the average of the distances between a behavioral tendency in Agent i and the perceived corresponding behavioral tendency in Agent j; if both agents are completely similar to one another, the value of similarity is 1.

Mathematical rule

$S^{ij}_{t} = 1 - \frac{\sum_{k=1}^{n} \left| B^{k,i}_{t} - B^{k,ij}_{t} \right|}{n}$ = Perceived similarity of Agent i for agent j, n=number of behavior

$B^{k,i}_{t}$ = Real behaviour of Agent i

$B^{k,ij}_{t}$ = Perceived behavior of Agents i and j

n= number of different behaviors

The perceived similarity at t+1 is calculated as one minus the average distance between the behavior of Agent i and the perceived behavior of Agent i for Agent j (what agent i thinks agent j is like).

1.5.5 Rules of preference

Conceptual rule

The preference that Agent i has for Agent j at time step t+1 is updated in the form of a logistic function. The next preference value equals the current preference value plus a change factor proportional to a parameter i and a parameter equal to the difference between one and the current preference value; the maximum preference value is one; the value of the parameter i depends on the similarity and the interaction of the agents.

Mathematical rule

$P^{ij}_{t+1} = P^{ij}_{t} + P^{ij}_{t} \times i \times (1 - P^{ij}_{t})$

P^{ij}_{t+1} = Preference that Agent i has for Agent j at time step t+1 (maximal preference possible)

i:= increase factor (depending on similarity and evaluation)

The property "preference" is updated as a function of the similarity and the interaction of the agents; this property has a direct effect on the evaluation of an agent on another agent.

1.5.6 Rules of mutuality

Conceptual rule

Mutuality between an Agent i and Agent j is defined as the shared preference of i and j, and is thus equal to the smallest preference of the two, i.e., the minimum value of the preference of i j and the preference of j for i.

Mathematical rule

$M^{ij}_{t+1} = \min (P^{ij}_{t+1} = P^{ij}_{t+1})$

M^{ij}_{t+1} = Mutuality of Agent i and Agent

$\min (P^{ij}_{t+1} = P^{ij}_{t+1})$ = minimum function of Preference that Agent i has for Agent j at time step t+1

The property mutuality is updated as the minimum function of preference of an agent to another agent and it has a direct relation with the interaction matrix.

1.5.7 Rules of interaction

Conceptual rule

The probability that two agents will interact at time t +1 is a random function of their mutuality.

Mathematical rule

$I^{ij}_{t+1} = rand\ (M^{ij}_{t+1})$

I^{ij}_{t+1}= Interaction of Agent i with Agent j

$rand\ (M^{ij}_{t+1})$ = random function depending on mutuality

The updating of the interaction is calculated on the basis of a random function depending on mutuality. In the model a random number between 0 and 1 is drawn from an even distribution. If this random number is smaller than the mutuality value, the interaction takes place, else not.

The value of the interaction between an Agent i and in Agent j is a random function of the total similarity between Agent i and A gent j.

$IV^{ij}_{t+1} = rand\ (S^{ij}_{t+1})$

IV^{ij}_{t+1} = Value of Interaction between Agent i and Agent j

$rand\ (S^{ij}_{t+1})$ Similarity of Agents ij at t1

The interaction value matrix is updated as a function of the similarity matrix. The random variable for the interaction value corresponds with a normally distributed random variable with the normalized true similarity as mean ($\mu = \frac{(S^{ij}_{t+1} - \theta_s)}{1-\theta_s}$) and the standard deviation is set to a fixed predefined parameter, σ_v that represents the standard deviation of the interaction value. In the model a random sample from this distribution is chosen by the computer and set as the interaction value. The similarity threshold θ_s is calculated as the average similarity value of all agents at time t+1.

1.5.8 Rules of popularity

Conceptual rule

Popularity is a function of the normalized value of total preference of all agents for another agent and it is calculated as the sum of the preferences divided by the number of agents -1.

Mathematical rule

$$Pop^{i}_{t+1} = \frac{\sum_{j=1}^{\#Agents} P^{ji}_{t+1}}{\#Agents - 1}$$

Pop^{i}_{t+1}= Popularity of Agent i

#Agents= number of Agents

Popularity is updated as a function of preference and it has a direct relation with the evaluation properties.

1.5.9 Rules of positive and negative evaluation

Conceptual rule

The evaluation of an ij interaction by Agent i, is a function the presence or absence of an interaction between the two agents, the popularity of Agent j, the value of their interaction, and the preference of Agent i for Agent j.

Mathematical rule

$E^{ij}_{t+1} = f\,(Pop^{j}_{t+1},\, I^{ij}_{t+1},\, IV^{ij}_{t+1},\, P^{ij}_{t+1})$

E^{ij}_{t+1} =Evaluation of Interaction between Agent i and Agent j

$f\,(Pop^{j}_{t+1},\, I^{ij}_{t+1},\, IV^{ij}_{t+1},\, P^{ij}_{t+1})$=linear combination of the four different terms that you need in order to calculate evaluation.

The property evaluation is updated as a function of interaction (value), popularity and preference and has a direct relation with behavior. For instance, the more an agent is popular, the more other agents increase their positive evaluation of him. The less an agent is popular, the more other agents increase their negative evaluation of him. The more positive interactions two agents have, the more they increase their positive evaluation of each other. The more negative interactions two agents have, the more they increase their negative evaluation for each other. The more an agent prefers another agent (likes another agent), the more he increases the positive evaluation of him. The less an agent prefers another agent, the more he increases the negative evaluation for him.

2. Summary and conclusion

In this chapter we presented a description of a mathematical model of friendship interactions and risk behaviors during adolescence, which is implemented in a particular way in the form of a simulation model written in Visual Basic. The model focuses on explaining the mechanisms that lead to the formation of groups of friends and eventually the increase in homogenous behavior. The simulation model consists of 20 individual agents. The agents are a simplification of real adolescents. The agents are characterized by ten short-term properties (behavior, perceived behavior, similarity, perceived similarity, preference, popularity, mutuality interaction, interaction value, and evaluation). The properties are based on theoretical and empirical findings. The short-term properties change over time by using simple rules expressed in the form of conceptual rules and mathematical formulas. After a number of model runs, the short-term model produces two main long- term properties, namely friendship and homogeneity of behaviors.

Our model is one of the first attempts that makes explicit, in a theoretical but also a mathematical way, the mechanisms that trigger the formation of groups of friends and their change in behaviors during adolescence, based on existing theories. The difference with the prevailing non-dynamical models is the dynamic nature of the principles used. In spite of the fact that their components are called “factors”, which suggests that they are components that do something or act upon something to change it, the non-dynamical models are basically concerned with describing static relationships between variables across populations. Instead, our model suggests and explicates the role of the positive evaluation of a friend as a motor of change and of adapting the behaviors towards those of the liked friend. Thus, the model does not only take into account the way different values of a *factor*, for instance having a certain amount of risk behaviors, are statistically explained by different values of homogeneity among friends. It attempts to explain *how* homogeneity emerges and develops in the course of time by providing a mechanism of change.

In this chapter we focused on describing the mathematical model, however, we did not yet describe what type of trajectories and processes the model produces and whether or not the model outputs correspond with the theoretical findings on which the model is based. Thus, arrived at this point a reader could ask: Does this model work? And what types of results does it produce? Are these results coherent with the theories and with available empirical data?
In the following chapter we will attempt to answer these questions by describing the results of the simulation and the qualitative analysis.

CHAPTER 4

A DYNAMIC SYSTEMS MODEL OF FRIENDSHIP INTERACTIONS AND RISK BEHAVIORS DURING ADOLESCENCE: THE SIMULATION AND THE QUALITATIVE ANALYSIS RESULTS

Nils Schuhmacher*
Laura Ballato**

**Department of Culture and Development, University of Osnabrück, Germany*

*** Department of Developmental Psychology, University of Groningen, the Netherlands*

INTRODUCTION

In the previous chapter we described a mathematical model that deals with the formation of friendship groups and homogeneity of behaviors during adolescence. In particular, we focused on the description of the properties of our model and the rules that make these properties change over time. In this chapter we will show that the model is able to reveal qualitative properties that were found in previous empirical research. Furthermore, we will show that the model is also able to explain the underlying processes that lead to friendship formation and change in behaviors. Specifically, the model has two main aims: The first one is to have explanatory power, the second one is to have predictive capability, where predictive is understood in a non-quantitative sense. In terms of Zeigler (1985) this predictive capability is related to the *structural validity* of the model which means that the model "not only reproduces the observed real system behavior [in terms of qualitative properties], but truly reflects the way in which the real system operates to produce this behavior" (p. 5). Additionally, the model can be used to experiment *in silicio*, i.e., to do experiments in the form of simulations (see also Epstein & Axtell, 1996). The model can be used as a laboratory to test certain system behaviors that can hardly be observed and/or tested in the real system. Thus, new scientific questions can arise from model experimentation, questions that can be answered empirically in subsequent stages of research.

However, we could argue: Is a model that is validated only qualitatively strong enough? As Troitzsch (2004) and Gilbert and Troitzsch (2005) said it is not always necessary for a valid model to predict results in a quantitative manner. They base this statement on the following arguments. First, a model with good quantitative predictions does not necessarily have to be a model with a high explanatory power. For instance, a model that predicts risk behaviors involvement of an adolescent from his friend behaviors, does not necessarily tell us about the underlying mechanisms of influence, only about the association between the two variables (i.e., risk behaviors of the adolescent and risk behaviors of his friends). Thus, its explanatory power is quite limited. Second, the quantitative analysis of a model in the social sciences and psychology poses more challenges compared to models in natural sciences. Data collection is mostly time-consuming and requires complicated tasks (e.g., multiple assessments, preventing participants drop-out; natural observations etc). However, a model can already be valid when it is able to explain real-world macro structures in a qualitative sense (Troitzsch, 2004). For instance, a model should not always include all factors that can influence the phenomena under study, but the general underlying mechanisms that lead to the formation of the phenomena. To check this form of validity an analysis in a qualitative manner is sufficient. Nevertheless, all simulations have to satisfy the requirements of explanatory as well as predictive power to a certain degree. Whether the simulation modeler emphasizes the desire for understanding or the need for making predictions (Gilbert & Troitzsch, 2005), an explanatory model should still be capable of making some predictions, though they might be not very precise (Gilbert & Troitzsch, 2005).

We will begin this chapter by explaining the verification of the model. Before letting the model run several hundred times, it is necessary to check the accuracy of the source code (i.e., the written program in Visual Basic) and if it works properly. This procedure is called model verification. Comparing the model results with observed data or empirical findings is called, instead, model validation (Gilbert & Troitzsch, 2005). This procedure will be done in section 3 of this chapter and in chapter 5. In this chapter, the model is validated by comparing its results with the theoretical and the empirical findings of the literature. The following chapter (chapter 5) will be dedicated to the validation of the model with the empirical data, collected for our research.

1. The verification of the model

The literature on verification, validation and model testing, specifically for Agent Based Modeling (ABM) is extensive (Balci, 1995; Fagiolo, Birchenhall, & Windrum, 2007; Gilbert & Troitzsch, 2005; Sargent, 1998; Troitzsch, 2004). Different approaches can be used to conduct the verification and the validation of a model and a variety of recommendations are given. However, concrete suggestions about the verification and validation for a specific model like the current model are rare. Thus, it was at the discretion of the modelers how to conduct the verification and the validation of the model. Many authors claim the need of systematic unit testing or assertion checking[1] (e.g., Gilbert & Troitzsch, 2005; Balci, 1995), which is a systematical comparison of "manually" calculated results (what you expect from your program to calculate or end up with) and what the program actually calculates. However, in our model these techniques were difficult to apply due to the fact that there are hardly any good unit testing frameworks for the programming language in which the model was made (Visual Basic for Applications (VBA) in Excel)[2]. Other ideas of verification were not feasible, mostly due to a lack of available human resources, e.g., a structured walk-through[3], in order to prove the validity of the model by letting the model be tested by a third party (Sargent, 1998) or re-implementing the model in a different programming language (Hales, Rouchier, & Edmonds, 2003).

The model verification ensures that the computer program works correctly. This means that no calculation errors or other kinds of "bugs" are present in the source code. In software engineering different approaches are used to test a program for possible errors: Object-oriented design, structured programming and modularity are approaches to avoid the appearance of bugs and to make it easier to find errors in the program code (Sargent, 1998).The model has been revised several times to improve the source code structure. Different verification techniques from software engineering have been used to check the correctness of the model (see for further details Schuhmacher, 2009). An intense period of debugging

[1] Normally a program is used for debugging the software. As there is no good program to do this in Excel, we did the assertion checking by hand (i.e., we calculated some values with a calculator and compared them with the model results).

[2] For a complete explanation of the model framework, see chapter 3.

[3] By structured walk-through we mean a formal method of debugging a computer system or program, involving a systematic review to search for errors and inefficiencies.

has been performed before model results have been analyzed. Most importantly, model functions have been proved for accuracy by comparing the functions' results with "manually" calculated test results.

In the end, the model verification was successfully concluded. The model has been carefully checked and no bugs or errors have been found. Therefore, it was ready for the next two steps: The simulation and the qualitative analysis.

2. Letting the model run: An updating cycle and simulation of a school year

The simulation consists of successive steps or also said "model runs". At each step, the properties are updated. This procedure is called a simulation cycle. In this section we will demonstrate how an entire updating cycle looks like within the model. Afterwards a complete simulation run, consisting of many successive models cycles, will be presented. We will begin by giving an overview of the models' properties and by showing how they are interrelated.

Figure 1 shows all major properties of the model. The circles indicate the different properties of the agents. The boxes contain the model parameters and thresholds (that can either be set to a fixed value or calculated as an average). The calculation rules for the agents' properties have already been introduced in the previous chapter (see chapter 3, page 58). Furthermore, figure 1 gives an impression of how the model states are interrelated and connected to each other indicated by the arrows. The dashed arrows de-

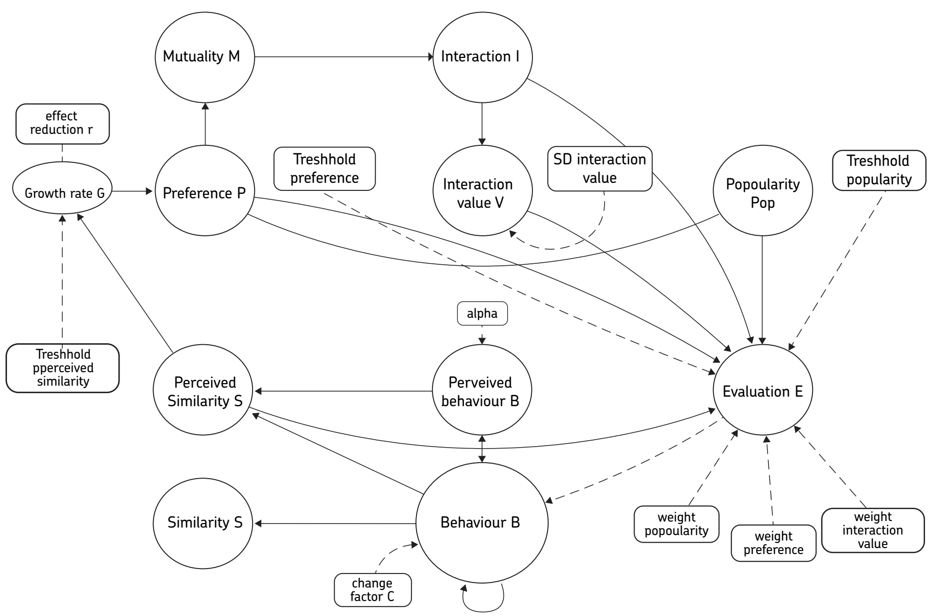

Figure 1. Model overview. The figure shows the main properties of the model and additional parameters. The arrows indicate the influences between the different properties.

note an influence by a parameter or threshold. The solid arrows report the influence between the agents' properties. To allow further inspection of the models' procedures, the next section presents a concrete example of the computations and the updating sequence of one simulation cycle.

2.1 A simulation cycle

Following figure 2, we will describe the updating sequence i.e., the simulation cycle or also called one step in the model. The first two computations during a simulation cycle are the updates of the similarity and the perceived similarity (update 1 and 2, *yellow*). As soon as the perceived similarity is updated, the growth rate for the preference and consequently the new values for preference can be calculated (update 3, *blue*). The values for mutuality as well as for popularity are refreshed on the basis of the new preference data (update 4 and 5, *blue*). After the determination of the mutuality values, the decision can be made whether two agents interact or not. Additionally, the value for these interactions is calculated (update 6 and 7, *green*). As the next major step within the updating cycle, the evaluation of the interactions can be performed (update 8, *violet*). As can be seen from figure 2, evaluation depends on many factors that have to be determined first. Therefore, the evaluation is calculated as one of the last states within the simulation cycle. The final updates consist of the calculation of the behavioral change due to the results of the evaluation and the change in the perception of the other agents' behaviors (update 9 and update 10, *light green*).

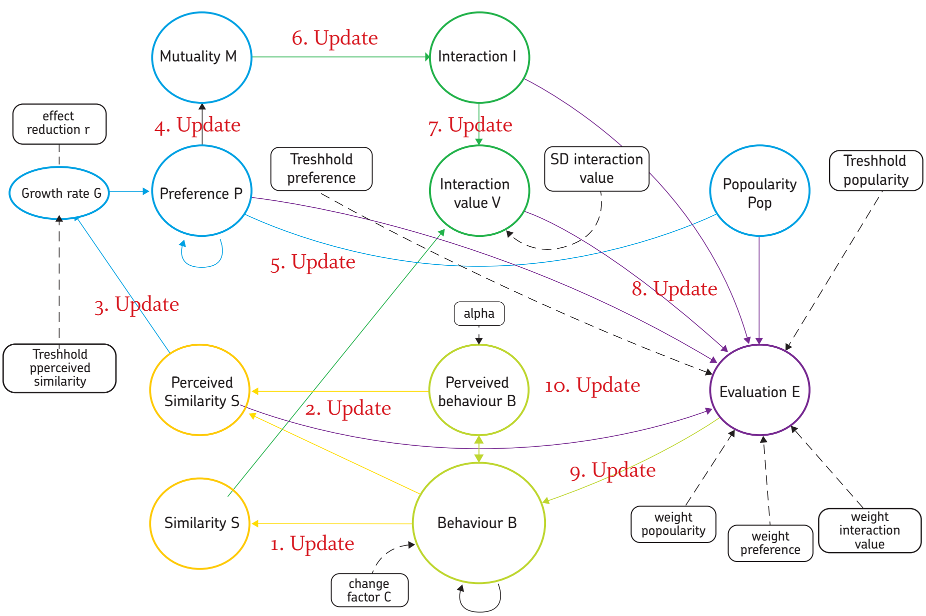

Figure 2. Updating cycle within the model. Numbers 1 to 10 show the sequence of updates within the model.

2.2 Simulation of a school year

In this section an example of a simulated school year is given (for parameter settings see appendix B). A school year is approximated with 200 days. Ten simulation steps shall represent a school day, 50 simulation steps represent a school week and 200 steps describe a month at school. The agents can have a maximum number of 10 interactions with another agent during a school day, so a total possible maximum of $10 \times 20 = 200$ (simulation steps per day × number of agents) interactions per school day. We have chosen 10 interactions because we assume that adolescents have a limited amount of meaningful interactions during a school day. Meaningful means that these interactions are non-trivial and submit at least a considerable amount of information that allows an adolescent to change his or her properties, e.g., the preference for a peer. Ten is an arbitrary number, but it expresses a choice of an average value out of a certain bandwidth of interaction frequencies, e.g., between 5 and 15 meaningful interactions per school day. There are 20 agents in the class. We assume that we start the simulation at the beginning of the school year. The class is newly formed; the agents have never met before.

2.3 Friendship network development

After the first day at school, when the agents have met for the first time, preferences and mutual preferences are formed. A friendship connection indicates a mutuality level > 0.8. Figure 3 shows the social network after the first day at school (t = 10). The possible interpretation for this initial friendship network is somehow limited, because the initial preferences were drawn randomly from an equal distribution with values from 0 to 1 for the underlying simulation run. For the further development of the preferences, the similarity plays a central role (see also page 60 of chapter 3).

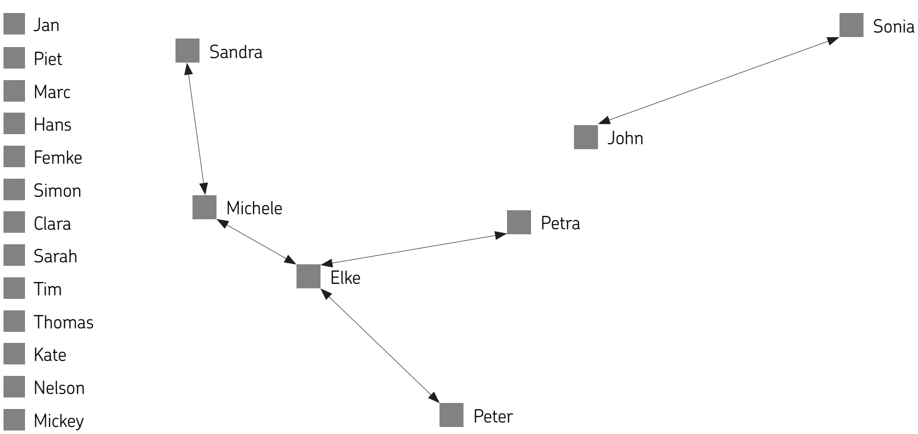

Figure 3. Friendship network (t = 10), showing many isolates and only a few initial friendship connections. The graph is a visualization of the mutuality matrix made with Netdraw (Borgatti, 2002). A friendship connection indicates a mutuality value > 0.8.

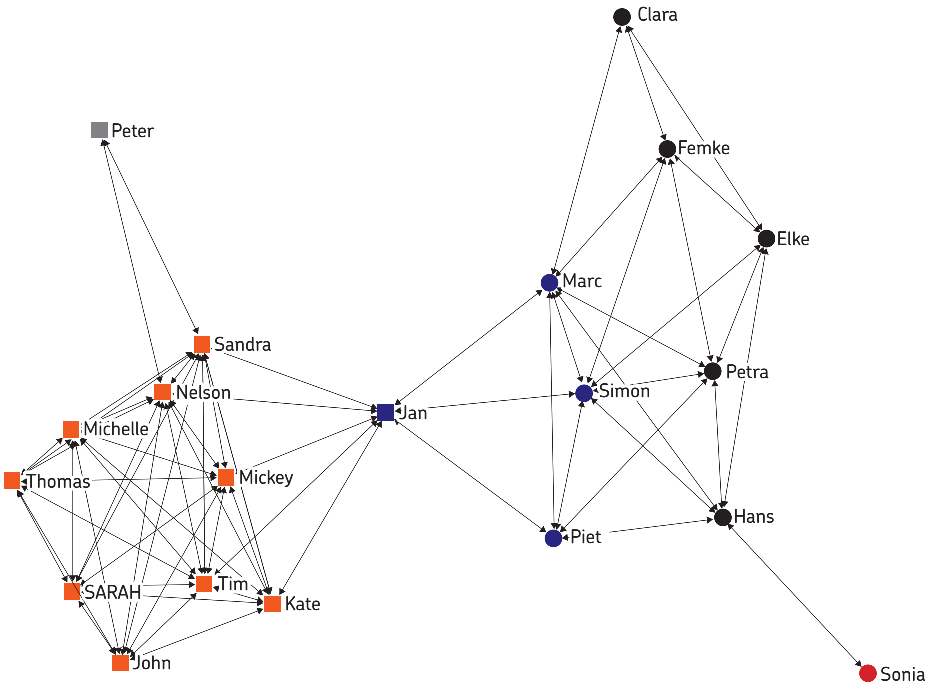

Figure 4. Emerging friendship network (t = 2000). The different colors indicate different clusters. See text for further explanations.

Figure 4 shows the resulting social network after 2000 simulation steps. On a first exploratory view it can be noted that a complex network emerged with the formation of two different groups (left and right). In general, the majority of the agents in the network are integrated in a group with multiple connections to the different group members. On a closer look further interesting details catch the eye. For instance, Jan seems to own a special position in this network. This agent has the role of a liaison (Ennett & Bauman, 1996), as he ties the members of two disparate groups. Without this agent there would be no connection between the groups left and right any longer. Jan, therefore, provides a channel of communication among the different groups. In terms of a strict definition of isolation (i.e., adolescents with no friends at all) (Ennett & Bauman, 1994), we can find no complete isolates in the given network. However, Sonia and Peter have only got very few friendship connections. Without her connection to Hans, Sonia would be isolated. Although Peter has two reciprocal friendships (one to Sandra and one to Nelson), he is not integrated in the friendship group. Ennett and Bauman (1994, 1996) define cliques as a small group of at least three adolescents closely connected with each other. Isolates are non-members of a clique (but they may have relatively few friendships connections and still be part of the overall social network). In this study, we defined an adolescent as isolated if he or she has got less than three friendship connections. Due to this definition Sonia and Peter are isolates in the current network.

As we can also see from the figure 4, some agents seem to hold a more central role than others. They have got more connections; therefore they can influence others more on the one hand, but also be influenced by a lot more agents on the other hand. In this case, an analysis of the degree of centrality in the network shows that Sandra and Nelson have the most central roles. Both possess ten friendship connections, they are connected to everyone in the group and additionally to Peter and Jan (who are not directly part of the two groups). When we have a look at the popularity results of our model run in table 1 and 2, we can see that Nelson also has the highest popularity value.

Table 1. *Popularity values of ten agents (t = 2000)*

AGENTS	Jan	Piet	Marc	Elke	Hans	Sonia	Femke	Simon	Clara	Petra
Poularity	0.6	0.37	0.44	0.39	0.5	0.34	0.44	0.48	0.35	0.41

Table 2. *Popularity values of the other ten agents (t = 2000)*

AGENTS	Sarah	John	Tim	Thomas	Kate	Michelle	Nelson	Peter	Mickey	Sandra
Poularity	0.5	0.55	0.54	0.48	0.6	0.51	0.62	0.41	0.57	0.54

When we compare the resulting social network at the end of the simulation with the initial network, we immediately recognize the enormous change that this network has undergone. At the beginning there were only few friendship connections and on the other hand a lot of isolates. Later on, a complex network with groups has emerged with agents having different roles within the network. Some friendships stayed stable (e.g., between Michelle and Sandra or Elke and Petra), others dissolved (e.g., Sonia and John) mostly due to the randomized initial preferences and the huge behavioral differences. In other words, the difference in the behaviors was too huge to stay friends.
Additionally it has to be mentioned, that the network presented in this section is one out of several possible results. As shown in chapter 3, the model is based on a stochastic process, i.e., random influences on the interactions occur at every iteration step. What we actually receive is a family or distribution of outcomes with certain qualitative characteristics. With the parameter ranges chosen for this example (see also appendix B) we on average receive a network like the presented one in figure 4. After 2000 simulation steps usually 2 to 3 groups emerge and in most of the cases initially isolated agents are assimilated into one of the friendship groups. This one result is, thus, fairly characteristic of what we receive after 2000 simulation steps, e.g., after 200 days in real life.

2.4 Simulation of the development of risk behaviors

The simulation of the risk behaviors development looks as follow: At about 1600 simulation steps, it seems that two behavioral groups emerge (see figure 5). One group has a moderately low average risk behaviors (about 0.4), the other group has a moderately high average risk behaviors (about 0.6). At the beginning of the simulation the variance in the individual levels of average risk behaviors seems to be high (compare to diagram between steps 0 and 200). Over the course of time this variance is decreasing, the agents tend to adapt their behavior reinforcing each other and therefore becoming more and more homogenous (see around step 1600). A special case in the graph seems to be the development of Jan. Though he has an initial low value for average risk behaviors, he does not seem to be reinforced by all the other agents having low risk behaviors. Contrariwise, he increases his risk behaviors. It seems to be the case that he has been attracted or influenced by the more risky agents.

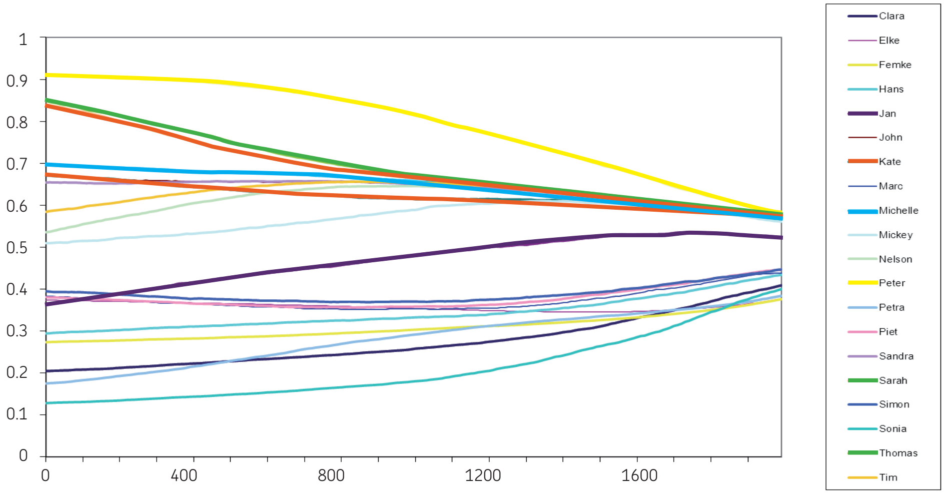

Figure 5. Development of average risk behaviors. The figure shows the development of the average risk behavior for the 20 agents in the model simulation (x-axis indicates simulation steps, y-axis indicates value for average risk behavior).

2.5 Friendship groups and behavioral homogeneity

Now let us combine the two former observations of friendship formation and development of behavioral profiles and have a look on how they are interrelated. As mentioned above an exploratory inspection of the network structure in figure 4 shows that two major groups have emerged. A hierarchical cluster analysis of the mutuality matrix at t = 2000 yields additional insights into the properties of the friendship network as shown in figure 4 and visualizes how the position in the social network and behaviors belong together. The shapes indicate the different behaviors (*circle, square*). A circle displays that the agent has an average risk behaviors smaller than 0.5 and an average conventional behaviors bigger than 0.5. The *square* means that the agent has an average risk behaviors bigger than 0.5 and an average conventional behaviors smaller than 0.5. The colors denote the *different* clusters of preference. Figure 4 shows the 5 biggest emerging clusters indicated by the different colors (*black, gray, blue, red, pink*). According to the findings above, the cluster analysis recognizes Peter and Sonia as isolates, too. The two major groups that we can define now on the basis of the cluster analysis are a risky group (*pink squares* left) and a conventional group (*blue* and *black circles* left). Jan belongs to the blue cluster left, though he shows more risk than conventional behavior (indicated by the square). This result again gives a hint about the special role of Jan, who seems to be a broker between the two worlds of risky and conventional agents.

We have now received a first impression of the possible results of the model. The focus of our interest in the model is the development of the friendship network, the different social roles in this network and how the friendship network can be related to the behavioral development. The results shown above give only a subset from a variety of possible model outcomes. At this point it has to be noticed again that that the model is a stochastic model, therefore the findings above could also be due to chance. These results must be considered one example. Different results can be obtained if we would have started the model with different parameter values. As we previously showed, the model yields a small number of friendship clusters as its typical result; quantitatively however these friendship clusters may differ in members and sizes along the different simulation runs; hence, what counts is the prediction of a small number of well-connected friendship groups, and not so much the quantitative prediction of friendship groups with specific composition. We can conclude that the model is able to predict formation of friendship groups and change in behaviors.

Our next step is to show that the model is in general able to reproduce data that are consistent with present empirical findings in social network analysis and development of risk behaviors in adolescence. In order to reach this goal different hypotheses were formulated and were tested in terms of a qualitative analysis of the model.

3. The qualitative analysis

In order to have validity the model should be able to reveal typical (qualitative) results from theoretical findings (for a complete overview of theoretical findings, see also chapter 2). In the following sections we wish to propose and test different hypotheses that reveal the validity of the model. First the hypotheses are formulated on the basis of research results that have been obtained in the area of adolescence development so far. The hypotheses shall be subdivided into two groups: Homogeneity hypotheses and influence/reinforcement hypotheses. In the next section, the various analysis methods for checking the different hypotheses are explained in more details. Finally, the corresponding model results of several simulation runs (with varying parameter settings) are presented to allow the confirmation or the rejection of the hypotheses.

3.1 Homogeneity hypotheses group

The homogeneity hypotheses group includes three sub-hypotheses: The group formation, the homogeneity and the dynamics of the emergence of homogeneity hypotheses. All three are described in the next sections.

3.1.1 Group formation hypothesis

Friendships in adolescence are mainly organized out of dyadic relationships. The dyadic relationships then interlink with each other to form more complex groups of friendship relations, mostly referred to as cliques[4] and crowds (Brown & Klute, 2003; Ennett & Bauman, 1994; Hallinan, 1979). Authors found out that a considerable amount (up to about 50%) of adolescents in school are actually member of a clique (Cohen, 1977; Coleman, 1961; Ennett & Bauman, 1994; 1996; Hallinan, 1979; Hallinan & Smith, 1989; Kandel, 1978). Ennett and Bauman (1996) stressed that there is a high variance in clique membership between the different schools. To them this could be a result of the varying school properties such as the number of students at the school, school location, school academic standing, student background characteristics, neighborhood content, amount of interaction of students outside school, how much students actually like school and the amount of extracurricular school activities. Hallinan and Smith (1989) found that the tendency to form cliques is dependent on the different structural characteristics of schools and school classes. Although data about the actual distribution of clique membership are vague and it is not absolutely evident which factors are responsible for the degree of variance between schools and a class, one aspect is clear: Adolescents tend to form friendship groups or "cliques". Consequently a major feature of the model should be that it is able to represent the emergence of such groups.

Using classical hypothesis formulation our first hypothesis is that the model is able to represent group formation:

- H_1: The model reveals emergence of distinct friendship groups.

In order to facilitate the testing phase, we are going to test the null hypothesis that is the model is actually not able to represent group formation.

- $H_{0,1}$: The model reveals no emergence of distinct friendship groups.

[4] In adolescence psychology literature, the term clique can have varying meanings and implications. For example, Ennett and Bauman (1994) use the following definition: "Cliques have a minimum size of three members. [...] Clique members are required to have most of their interaction (>50%) with members of the same clique and at least two links with others."(p. 656). The definition of a clique in Social Network Analysis (SNA), however, is quite clear: A clique is defined as a "maximal complete sub-graph" in a social network, i.e., in a clique all members need to have a tie/connection to all other members of the clique. As many actors as possible are included into a clique, so that all actors have all possible ties present among themselves (Hanneman & Riddle, 2005). The definition of a clique used in this work shall be a little bit different from the standard definition. In order to avoid overlapping membership and to define different friendship clusters, we used a hierarchical cluster analysis (See hypotheses 3,4,5 of section 3.3). Overlapping membership means: An agent can be a member of different cliques, and not a member of only one clique. For example the agent can be member of clique 1 and clique 2, so the agent has an overlapping membership. In a hierarchical cluster analysis every agent belongs only to one cluster/group at the same time. Therefore, we will refer to the term friendship group (or cluster) instead of clique or use the term in parentheses ("clique"). The effect of this approach is that an agent can be assigned only once to a group (or cluster) on the basis of the hierarchical cluster analysis, so an agent cannot be a member of two or more distinct clusters at the same clustering level. Agents ascribe to the same cluster have similar or equivalent social relationships. To be a member of a cluster, an agent does not need to have a tie to all other members of the cluster, but in general cluster members need to have a similar pattern of relationships. Additionally, the hierarchical clustering gives us the possibility to ascribe agents to a cluster on different levels because small clusters are agglomerated to bigger clusters or units in the analysis. In this sense our definition of a "clique" is a little bit weaker than the definition in SNA described above and is closer to the definition used by many adolescence researchers (e.g., Brown & Klute, 2003; Ennett & Bauman, 1994; Hallinan, 1979).

3.1.2 Homogeneity hypothesis

As described in chapter 2, researchers have often investigated the homogeneity in dyadic friendships and friendship groups (Byrne, 1971; Cohen, 1977; Ennett & Bauman, 1994; 1996; Kandel, 1978). Adolescents tend to be similar in their conventional behaviors as well as in their risk behaviors. Many researchers had a special interest for homogeneity tendencies in risk behaviors (see Schulenberg *et al.* (1999) for peer influences on drinking behavior; Espelage, Holt and Henkel (2003) on homogeneity in aggressive behavior; Ennett, Bauman and Koch (1994) for homogeneity in smoking behavior; Patterson and Dishion (1985) for homogeneity in delinquent behavior and Kandel and Davies (1991) for homogeneity in illicit drug use). However, there are also similar findings on homogeneity in conventional behaviors. Henrich, Kuperminc, Sack, Blatt and Leadbeater (2000) could find considerable homogeneity for school adjustment. Jessor, Turbin and Costa (1998) found that peers who model conventional behavior tend to be a protective factor for a particular adolescent's own health behavior.

In line with these theoretical findings, our model should be able to simulate and explain a connection between the distance or closeness between the agents in the friendship network and their behavioral profile, indicating that agents standing closer together in the social network (i.e., being friends) also tend to have similar behaviors. Following the logic explained above, we formulate the second hypothesis and null hypothesis:

- H_2: The model reveals a relationship between the behavioral attributes and distance between friends in the social network (small distance-high behavioral similarity).
- $H_{0,2}$: The model reveals no relationship between the behavioral attributes and distance between friends in the social network.

3.1.3 The hypothesis on the dynamics of the emergence of homogeneity

The third and last hypothesis in this section is about the dynamics of the emergence of homogeneity. The assumption is that agents change or adapt their behavior faster in the beginning than at the end of the simulation. Findings from empirical researches indicate that the change in homogeneity in established friendships is lower than compared to non-stable friendships (i.e., friends to be at time 2) (Kandel, 1978). Although Kandel (1978) did not explicitly test it, her data showed that friends-to-be at time 2 changed their frequency of marijuana use, their educational aspirations and minor delinquency more compared to adolescents in established stable friendships. Another evidence for this assumption is related to the findings of Bot, Engels, Knibbe and Meeus (2005). The authors found that for adolescents' drinking behavior the behavioral change in established and reciprocal friendships was lower compared to unilateral friendships. This can be explained as follows: Because mutual friends already have got a very high level of similarity the behavioral change by influencing each other is relatively low.

In summary, as regards the resulting friendship network, we expect to see that the different group members have changed their behaviors more in the beginning than at the end of the simulation, which in reality is the school year covered by the simulation. Therefore, the decrease of the behavioral variance[5] (within a group) should be faster in the beginning than in the end. The corresponding hypothesis and null hypothesis looks like follows:

- H_3: The model reveals a difference between the initial and final decrease of behavioral variance within the groups.
- $H_{0,3}$: The model reveals no difference between the initial and final decrease of behavioral variance within the groups.

3.2 Influence and reinforcement hypotheses

In addition to focusing on similarity as a major factor for friends selection, there has been a considerable amount of research on peer influence during adolescence. The following groups of hypotheses deal with the concept of influence and reinforcement.

In her pioneering work, Kandel (1978) recognized that similarity in certain behaviors among friends cannot be explained only on the basis of influence. Today many researchers claim that the impact of peer pressure has initially been overestimated and homogeneity is explained on the basis of the processes of similarity as well as influence (Burk, Steglich, & Snijders, 2007; Engels, Ennett & Bauman, 1994; Knibbe, Drop, & de Haan, 1997; Hoffman, Monge, Chou, & Valente, 2007). The similarity/ influence hypothesis has been formulated by using Social Network Analysis (SNA). SNA tries to investigate the relative impact of the two processes similarity and influence on behavioral homogeneity.

As we said in chapter 2, an operationalization of the term peer influence is difficult to find. Many researchers use the term peer influence in the sense of peer pressure. Peer pressure indicates that adolescents are forced to behave in a certain way to become or remain a member of a group. The source of the pressure lies in the other group members. But which role does the "influenced" person play in this context? Findings of this direct pressure are rare (see Arnett, 2007). As Arnett (2007) states the term "influence" is mostly used due to a statistical association between the behavior of an adolescent and his or her friends. The problem is clear: Correlation does not necessarily say anything about causation.

In order to facilitate an operationalization of peer influence, our model makes a clear distinction between influence and reinforcement. Influence refers to a discrete change, more precisely a change that brings an agent from not-involvement to an involvement in a particular behavior (e.g., smoking). For example, for a particular risk behavior, the agent has a beginning level of zero (e.g., he does not smoke). After a number of interactions with another agent, the first agent will have become involved

[5] For the analysis, the standard deviation is actually calculated instead of the variance. This has no further influence, because if the analysis results hold for the standard deviation, they also hold for the variance.

in some risk behavior (for example, he will smoke a few cigarettes). If this occurs, then influence takes place. Reinforcement, on the other hand, is indicated by a gradual change (continuous change) from some level of involvement to another level of involvement. For example, two agents with qualitatively similar risk profiles but different level of involvement start to interact. If after a number of interactions, both agents end up having the same level of risk behaviors, then reinforcement has occurred. The transitional character of the change (the absolute difference) determines if influence or reinforcement occurs: A transition from nothing to something, due to the interactions with some other person, is a process of influence. A transition from some level (e.g., low, medium, high) to another level (e.g., from medium to high) due to the interactions with a particular person (who himself has a high level of the property) is called reinforcement.

According to the explanations and findings so far, the model should be generally able to show cases where agents are influenced, e.g., at the end of the simulation, an agent with initially low risk behaviors has become a member of a group with moderate or high level of risk behaviors. Therefore, the hypothesis and null hypothesis for the influence process are:

- H_4: The model generates cases of influence.
- $H_{0,4}$: The model generates no cases of influence.

Although influence occurs, most of the agents will actually not be influenced, but be reinforced, thus stabilizing their behavior within a corresponding group of similar agents. The hypothesis and null hypothesis for the reinforcement process then look like follows:

- H_5: The model will generate reinforcement for a majority of cases.
- $H_{0,5}$: The model will not generate reinforcement for a majority of cases.

3.3 Procedure and data analysis methods

As mentioned above, the model validation is a challenging part that needs analysis methods adapted to the characteristics of the model at hand. For each hypothesis presented above a separate method for testing has been used. These methods are not always common in classical psychological analysis and are mainly adopted from SNA.

Seeing our computer model as a "chance" machine, the results that the model produces could be due to an accidental finding or just random influences. In order to avoid these possibilities, we checked if an observed phenomenon (e.g., the building of friendship groups) is just due to an accidental sample or really a qualitative property of our model by using Monte Carlo simulation technique (see also Steenbeek & van Geert, 2008). The general logic of a Monte Carlo simulation is as follows: "Using a given data-generating mechanism (such as a coin or die) that is a model of the process you wish to understand [in our case the simulation computer model], produce new samples of simulated data [our model results], and examine the results of those data [what is actually done in our analysis]" (Simon, 1997, p. 154).

Twelve parameters were randomly drawn from an equal distribution over a corresponding parameter range (that is more or less suitable in order to be able to observe the phenomena we would expect; see also appendix C). The ranges were defined either based to empirical findings or estimated on the basis of theoretical considerations or the modelers experience from several model tests runs (see appendix A for the parameter ranges and their estimation). These parameters are then used to run a great number of simulations, each of which generates a particular model output. After the model output is generated, the analysis procedure is as follows: For every simulation result the value for the observed phenomenon of interest is calculated (e.g., a value indicating the tendency of building friendship clusters). For these variables of interest further statistical analysis is then conducted. In some cases, a specific form of a Monte Carlo analysis (i.e., permutation test) is used (for further details see below). For significance reasons actually 1000 up to 10000 runs should be made. Due to computational limitations only 100 model runs have been executed and 100 runs were analyzed (one model run took about 9 minutes, 1000 model runs consequently 9000 minutes = 6.25 days). We decided to make 100 model runs because in our view this number represents the best compromise between the limit of the computational resource and the reliability of the model. For results close to statistical significance (e.g., indicating a significance level between 0.15 and 0.05) an additional analysis with more simulations should be made to be able to state the significance of the results. For results clearly indicating the rejection of the null hypothesis (e.g., $p < 0.01$) or clearly recommending the perpetuation of the null hypothesis (e.g., $p > 0.2$) it is not expected that performing more simulation runs will actually change the level of (non) significance.

As we said earlier we are going to test only the five null hypotheses. For testing hypothesis $H_{0,1}$ (i.e., the model reveals no emergence of distinct friendship groups), we considered the clustering coefficient originating from SNA a suitable measure indicating group formation or cluster building. The cluster coefficient measures the tendency of a network to build dense local neighborhoods or “clustering”. The local neighborhood of an agent A includes all the agents that are directly connected to A. The density of this neighborhood is calculated by the ratio of the present links between all the agents in the neighborhood (leaving out agent A) divided by the number of all possible connections between the agents in the neighborhood. The overall clustering coefficient is then the average of all local neighborhoods of all agents. To accurately interpret this value the overall network density has also to be considered. The overall network density is calculated as the amount of actual ties between the agents in the network divided by the amount of all possible ties in the network. To assess the degree of clustering in the network we divide the overall clustering coefficient by the overall network density (Hanneman & Riddle, 2005). The resulting clustering degree shall be a measure for group formation. The clustering degree is calculated on the basis of the dichotomized mutuality matrix[6] after 2000 steps representing the friendship network. Due to our null hypothesis the clustering degree

[6] A dichotomized matrix has only got 1 and 0 as entries, 1 indicating a tie between the two corresponding agents, 0 indicating the absence of a tie. To dichotomize the mutuality matrix all entries bigger than or equal to a certain threshold were set to 1, all values smaller than the threshold were set to 0. In this case the threshold was set to 0.8. Therefore, to be really able to speak of a friendship between two agents their mutuality value had to be bigger than or equal to 0.8.

should be 1, saying that the local network density and the overall network density actually are the same, so no tendency of building distinct groups in the data is given, or 0, indicating that all agents are isolated or only isolated dyadic friendships exist, so actually no friendship groups emerged. A value significantly bigger than 1 indicates clustering or formation of distinct groups. If the model produces a clustering degree > 1 in only 5% or less of the cases (e.g., due to a model error), we will confirm to the null hypothesis. Otherwise we will reject it. In other words, based on the null hypothesis we would expect that the probability *p* of the model to deliver results with a clustering degree > 1 should not be bigger than 0.05. We are going to check this result using a permutation technique.

For testing the second null hypothesis (i.e., $H_{0,2}$: The model reveals no relationship between the behavioral attributes and distance between friends in the social network), a statistic originating from geography is used: The Moran "I" spatial autocorrelation statistic. This value can be interpreted as correlation value with a value about 1 indicating high correlation, between proximity and similarity in the network, 0 indicating no correlation and -1 negative correlation (in this text we will call the Moran "I" spatial autocorrelation statistic as: Moran "I" proximity-similarity statistic). In geography the Moran "I" proximity-similarity statistic has been used to check the extent to which the similarity of the geographical features of any two places is related to the spatial distance between them. For example, you could check whether you find a certain kind of fauna only in certain areas. Adapted to social network analysis we would like to check whether the distance between agents in the network is correlated with some of their attributes. In our case we ask: Do agents close together in the network show similar behaviors? The Moran "I" proximity-similarity statistic gives us a value for the proximity-similarity measure between a certain attribute and the spatial distance of the occurrence (Hanneman & Riddle, 2005). In our case we are interested in the question: Are more risky agents also standing closer together in the social network? The second null hypothesis says that no such correlation exists, so the correlation should be about 0 (or in most of cases not be significantly different from 0).

For checking the last hypothesis of the homogeneity section (i.e., $H_{0,3}$ the model reveals no difference between the initial and final decrease of behavioral variance within the groups) a bootstrap method is used. First the different friendship groups were defined on the basis of a hierarchical cluster analysis. An a priori number of four groups is assumed, so the four biggest clusters are actually given. If a cluster has less than three members, it is not included for further analysis. Secondly, for each group the following steps are taken. The standard deviation for the average risk behaviors and the average conventional behaviors is calculated for two different points in time during the beginning of the simulation run ($BehSD_{t1}$,$BehSD_{t2}$, e.g. ,with $t1 = 400$ and $t2 = 800$) and for two different time steps at the end of the simulation run ($BehSD_{t3}$,$BehSD_{t4}$, e.g., with $t3 = 1600$ and $t4 = 2000$). Then, the average change of the behavioral standard deviation (SD) in the beginning is calculated as the difference of $BehSD_{t2}$ and $BehSD_{t1}$ (ABC[7]$1 = BehSD$t2 - $BehSD_{t1}$) and the average change of the behavioral *SD* for the end of the simulation is calculated as the difference of $BehSD_{t4}$ and $BehSD_{t3}$ ($ABC2 = BehSD_{t4} - BehSD_{t3}$). We use the

[7] ABC= Average Behavioral Change

average change of the behavioral *SD* as a measure of the amount of change because if we see that the standard deviation e.g., of the risk behaviors within a friendship group decreases over time, this indicates that the people within this group become more and more homogenous. To check if the average change in behavioral *SD* within a group at the beginning is the same as at the end, we calculate the difference of *ABC1* and *ABC2* ($\Delta SD = ABC1 - ABC2$). Due to the null hypothesis ΔSD should be 0 or not be significantly different from 0 showing that there is no difference between the change of behavioral *SD* in the beginning and at the end of the simulation. A value of $\Delta SD > 0$ would indicate a decrease in the change of behavioral *SD*, $\Delta SD < 0$ would indicate an increase in change of behavioral *SD* (so the standard deviation even grows faster at the end). To evaluate the significance of ΔSD we use the bootstrap technique (resampling) (Moore & McCabe, 2006).

To check the null hypotheses on influence and reinforcement (i.e., $H_{0,4}$ and $H_{0,5}$ the model gives no cases of influence; the model will not represent reinforcement for a majority of cases), the following analysis method is applied: First a hierarchical cluster analysis has to be conducted to define groups at the end of a simulation ($t = 2000$). Groups with less than four members are excluded from further analysis. Then the initial group means for average risk behaviors and average conventional behaviors are calculated ($M_{i,t}$ for $t = 10$ and group i). If the initial behavioral value of an agent that is a member of group i at t = 2000 is actually closer to a group mean $M_{j,10}$ of a different group *j* than to the mean $M_{i,10}$ of his own group *i*, this is understood as a case of influence. Else the agent is said to be reinforced by the other agents.

3.4 Results

3.4.1 Clustering degree

In 12 cases of the 100 model runs the overall density was the same as the clustering coefficient: The degree of clustering was 1. In these cases a maximal network emerged, where every agent was connected to all other agents. In none of the cases all agents have been isolated at the end of a simulation (clustering coefficient equals 0). Most of the simulation results yielded a moderate degree of clustering, on average the local neighborhood density was about double the size of the overall density (M= 2,14).

Figure 6 shows the frequency distribution for the different values of the clustering degree. As you can see from the figure 6 that a value for the clustering degree between 2 and 2,5 are most frequent (50 times).

On the basis of the simulation results the first null hypothesis (i.e., $H_{0,1}$ the model reveals no emergence of distinct friendship group) must be rejected. Given a binomial distribution the probability of 88 successes (clustering degree > 1) or more out of 100 trials with a success probability of 0.05 is smaller than 0,001 ($p < 0.001$). The 95% confidence interval for the success probability parameter p of the binomial distribution was calculated and is $79.98\% \leq p \leq 93.64\%$. Therefore, the probability of a clustering degree bigger than 1 lies with 95% confidence between 79.98% and 93.64%. The second question is: How good does the model represent group formation? If we choose a clustering

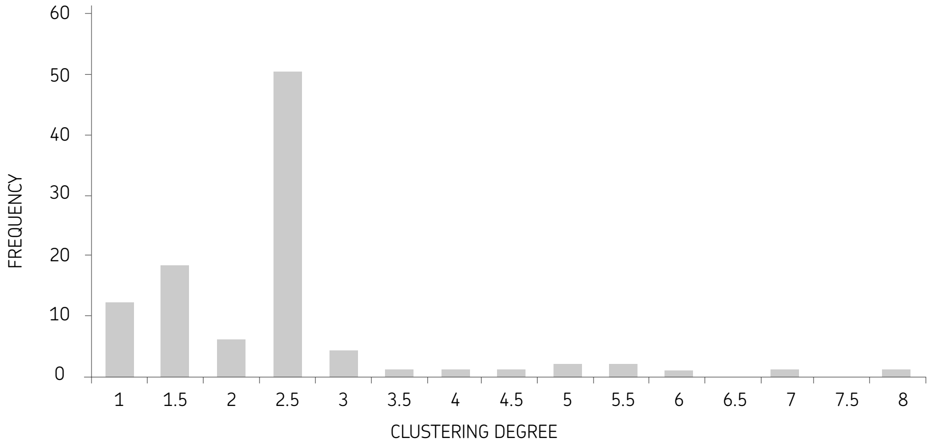

Figure 6. Frequency distribution of the clustering degree from the 100 simulation runs.

degree of 1,6 as a cut-off value indicating a moderate degree of clustering, we achieved 69 successes (clustering degree > 1,6) out of 100 trials. The 95% confidence interval for the true underlying success probability p that the clustering degree is bigger than 1,6 is between 59.01% and 77.84%. Therefore, with a confidence of 95% the model reveals results with a clustering degree indicating moderate or better level of distinct group formation with a probability p between 59,01% and 77,84%.

Additionally, one could claim that the clustering degree was already been present, in other words the model has actually done nothing to deliver these results. To check this possibility, we performed a permutation test (1000 runs) and checked whether the average clustering degree at the beginning of the simulation ($t = 10$) differs significantly from the average clustering degree at the end ($t = 2000$). The test reveals a highly significant difference between the average clustering degree at the beginning and the average clustering degree at the end ($p < 0.001$).

3.4.2 Moran "I" proximity-similarity measure and average risk/conventional behavior and closeness in the network

As mentioned above, in order to check a possible interrelation between the behaviors and closeness in the friendship network the Moran "I" proximity-similarity statistic was applied to the 100 simulation results. On average the Moran "I" proximity-similarity statistic between average risk behaviors and closeness in network was 0,76. In most of the cases the Moran "I" proximity-similarity measure lays between 0,8 and 1,0 (see also figure 7). There have only been 6 cases where results did not reach significance level ($p > 0{,}1$). In 7 cases the Moran "I" proximity-similarity statistic did not reveal a number (NaN) due to a division by zero error (see also below for explanation). All other results reached at least a significance level of $\alpha = 0{,}05$ or better (see figure 7).

In a next step we compared the results of the clustering degree with the ones of the Moran "I"

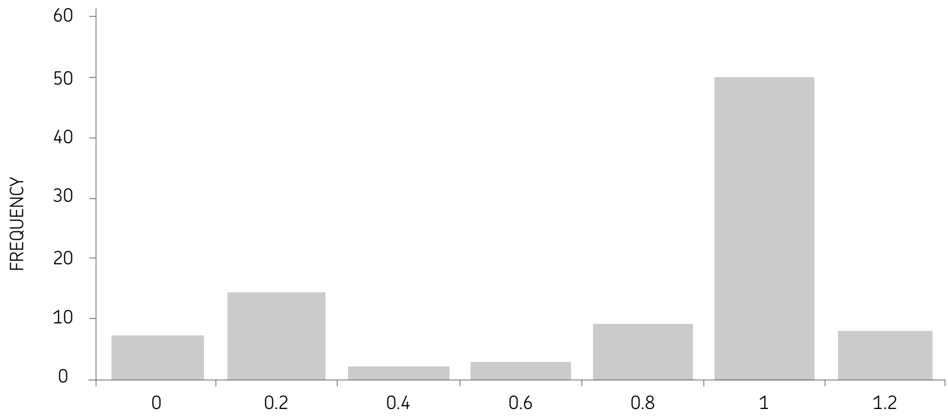

Figure 7. Frequency distribution of the Moran "I" proximity-similarity values for average risk behavior (100 model runs)[8].

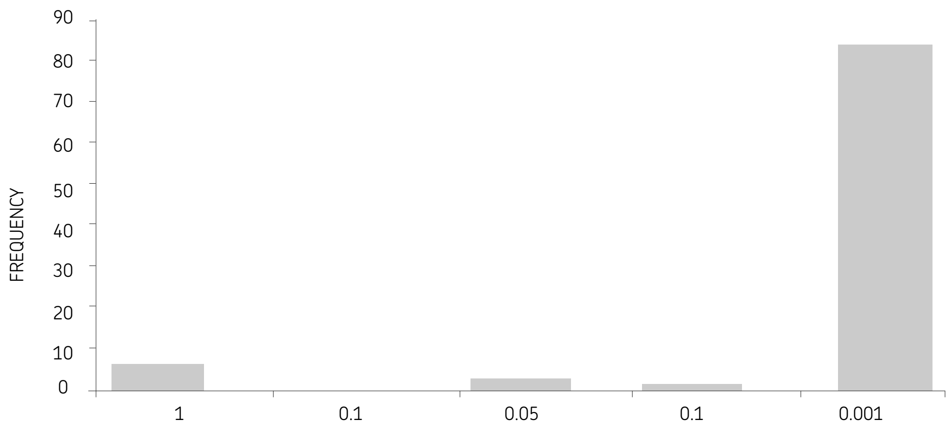

Figure 8. Distribution of the significance levels for the different results of the Moran"I" proximity-similarity statistic for average risk behavior (100 model runs).

proximity-similarity measure. In 12 cases the clustering degree was smaller than 1.4 and the Moran "I" proximity-similarity measure smaller than 0.3, but the significance level was still high ($p < 0.001$) (see figure 6). In 2 cases the clustering degree was also low (smaller than 1.4) still reaching a good level of significance ($p < 0.05$). In 5 cases we had a clustering degree of 1 and the Moran "I" proximity-similarity statistic did not become significant ($p > 0.3$). In these cases only one big

[8] As can be seen from the figure there have been 8 cases where the Moran "I" proximity-similarity measure became slightly bigger than 1 though Hanneman and Riddle (2005) claim that the values should only vary from -1,0 to 1,0. In spite of an intense search on this issue, an explanation for these results couldn't be found yet.

homogenous friendship group emerged and the behavioral variance was very small. In 7 cases the clustering degree was 1 or very close to 1 (indicating that a maximally homogenous friendship group emerged) and the behavioral variance became 0, so the Moran "I" proximity-similarity statistic could not be calculated any longer (calculation of Moran's "I" delivered NaN[9]). In 3 cases we had a high degree of clustering and a low level of Moran "I" proximity-similarity measure. In one case the result fell even below significance level ($p = 0.14$). This case indicates a formation of mixed groups consisting of agents with low as well as high risk behavior.

To sum up the results: In 87% (see figure 8) of the cases the Moran "I" proximity-similarity statistic between the average risk behaviors and the closeness in the friendship network was significantly different from 0. Again, if we allow a maximal probability $p = 0.05$ for accidental cases of a correlation significantly bigger than 0, the null hypothesis has to be rejected ($p < 0.001$). Therefore, the probability of the model revealing a Moran "I" proximity-similarity statistic significantly different from zero is bigger than 5%. The confidence interval for p indicates that the true probability of the model (for the given parameter ranges) lies with 95% chance within 78.80% and 92.92%.

The results for the comparison with average conventional behavior are comparable. In this case, the average correlation here was 0.76. In 4 cases results did not reach significance level ($p > 0.1$). In 8 cases results were not available, because the Moran "I" proximity-similarity statistic could not be calculated due to division by zero (see also above for an explanation). In all other cases (88%) results reached at least a significance level of $\alpha = 0.05$ or better. The results also showed a success probability (where success means a positive correlation that is significantly different from 0) significantly bigger than 5% ($p < 0.001$). The 95% confidence interval for the true success probability p is between 79.98% and 93.64%.

On the basis of the results the second null hypothesis (i.e., $H_{0,2}$ The model reveals no relationship between the behavioral attributes and distance between friends in the social network) must be rejected.

3.4.3 Different decrease in behavioral standard deviation

In order to check the third null hypothesis of the homogeneity group ($H0,3$ the model reveals no difference between the initial and final decrease of behavioral variance within the groups) the change of the behavioral standard deviation at the beginning of a simulation ($t1 = 400$, $t2 = 800$) was calculated and compared with the change of the behavioral standard deviation at the end of the simulation ($t3 = 1600$, $t4 = 2000$). This was done to check whether the behavioral standard deviation within a group decreases faster in the beginning than in the end of a model simulation. Our assumption was that friends adapt faster to each other at the beginning of a friendship than at the end.

The difference in the change of the behavioral standard deviation at the beginning and at the end is indicated with ΔSD. A positive value ΔSD denotes that the change of the deviation at the

[9] NaN means Not a Number and is a typical error message in programs (in this case in the R statistic program). NaN means that the program could not deliver a number due to an error in the calculation, in this case the behavioral variance became 0. Therefore the term in the denominator for calculating Moran "I" becomes 0, so Moran "I" can not be calculated.

beginning is bigger than at the end. Δ*SD* has been calculated for the 100 model runs. A hierarchical cluster analysis has been conducted for each model result to define the different groups and its members that have emerged at the end of a simulation. Only groups with more than three members have been considered in the analysis. The analysis has been made for each group and separately for average risk within the group. Figure 9 shows the distribution of the Δ*SD* values for the average risk behavior. In 23% of the cases Δ*SD* has been smaller than or equal to zero. In 77% of the cases Δ*SD* has been bigger than 0 (*M*= 0.0271, *SD* = 0.0263). For the average conventional behavior Δ*SD* was in 24% of the cases smaller than or equal to 0, in 76% of the cases it has been bigger than 0 (*M*= 0.0261, *SD* = 0.0253). In terms of an underlying process this could mean that we have found a kind of "discrepancy-proportional peer influence" as explained by Boxer, Guerra, Huesmann and Morales (2005). Friends that are more different e.g., at the beginning of a friendship influence each other more than friends who have an established friendship.

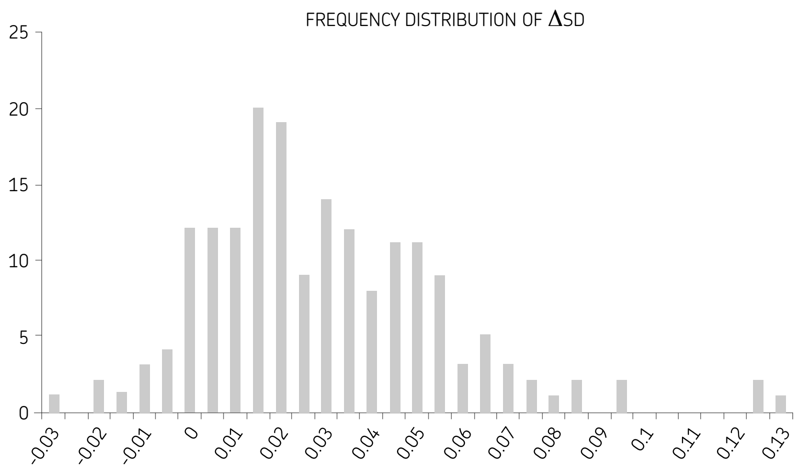

Figure 9 . Frequency distribution of ΔSD for average risk behaviors.

To prove that Δ*SD* is significantly bigger than 0, a bootstrap (resampling) technique was used. We proceeded in the following way: First we resampled the data (100 iterations) with the help of PopTools (Hood, 2010) and then we checked the confidence interval of the "resampled means". The result shows that the 95% confidence interval is between these two values: 0.0235 and 0.0309. Because 0 is not within this confidence interval, Δ*SD* seems to be significantly different from 0. In other words, in the model the decrease in behavioral variance within the groups is stronger at the beginning than at the end. Null hypothesis three (H0.3) can thus be rejected.

3.4.4 Influence and reinforcement

For the average risk behaviors, results from the 100 model runs (100 model runs × 20 agents = 2000 cases) revealed influence in 102 cases (5.1% of all cases). In 272 cases (13.6% of all cases) agents were not a member of a group or member of a group with less than 4 members. This means that no group was formed at all. As already mentioned above, these agents have been excluded from the analysis of influence and reinforcement. The majority of the agents were reinforced in their average risk behaviors (1626 or 81.3% of all cases). In 29 out of the 100 model runs we receive at least one case of influence (so the amount of influenced agents in 29 out of 100 model runs was 1 or bigger). In 97 out of the 100 model runs we obtained 10 or more cases of reinforced agents. For the conventional behaviors the results show a similar picture: 101 cases of influence (5.05%), 1627 cases of reinforcement (81.35%) and 272 (13.6%) excluded cases. In 98 out of the 100 model runs we have 10 or more cases of reinforcement; in 31 runs we receive at least one case of influence.
Table 2 shows averages and standard deviations for the influence and reinforcement cases.

Table 2. *Averages and standard deviations for influence and reinforcement cases in average risk and average conventional behaviors*

		Risk Behaviors	Conventional Behaviors
Influence	*M*	1.02	1.01
	SD	2.2	2.09
Reinforcement	*M*	16.26	16.27
	SD	2.16	2.06

This table clearly shows that the probability for having one case of influence or more within a simulation run is significantly different from 0 (with $p = 0$ meaning that absolutely no cases of influence occur) for average risk behaviors ($p < 0.001$) as well as for average conventional behaviors ($p < 0.001$). Therefore, $H_{0,4}$ (i.e., the model gives no cases of influence) has to be rejected. The 95% confidence interval for the true underlying probability of receiving one or more influence cases for average risk behavior is between 21.26% and 38.9% and for average conventional behavior between 23.08% and 40.97%. The probability of seeing more than 10 cases of reinforcement in a simulation result is significantly bigger than $p = 0.5$ for average risk behavior ($p < 0.001$) as well as for average conventional behavior ($p < 0.001$). So $H_{0,5}$ (i.e., the model will not represent reinforcement for a majority of cases) has to be rejected (if we define majority as more than 50% of the agents), too.

4. Summary and conclusion

To recapitulate, the model has three major aims. First, it should be able to sufficiently reveal typical qualitative properties found in empirical research so far. Secondly, it should have explanatory power and finally, it should be possible to use the model as an experimental laboratory to test certain assumptions *in silicio*. To check whether the model is sufficiently valid, several hypotheses were postulated and tested with different methods. Although we have started our chapter by claiming that our validation was mainly qualitative, we wish also to emphasize that the qualitative validation presented in this chapter is based on rigorous statistical numerical procedures and has been preceded by a verification of the model.

The question now is: Do the results give evidence that the model is indeed sufficiently valid? In short, the answer is yes. However we have to be aware of certain problems and limitations of the model, which we will now explain in detail.

In this chapter we tested five hypotheses, three of which deal with the concept of homogeneity and two with the concept of influence and reinforcement.

The first hypothesis dealt with the question: Does the model reveal a considerable amount of group building, i.e., clustering? The results have shown that with a probability about 60% to 80% a moderate or better clustering degree is reached. On average the local neighborhood density had twice the size of the overall density. This result in general suggests that on average two dense clusters (or friendship groups) have emerged. The results also indicate a variety of possible outcomes, e.g., the clustering degree shows values between 1 and a maximum value of about 8. Therefore, the model seems to be able to produce a certain spectrum of emerging social networks. This variability is also a characteristic of real emerging social networks (Ennett & Bauman, 1996). A potential problem of the model might be that in 20% to 40% of the cases the clustering degree became relatively small (smaller than 1.6) indicating high connectivity between the agents. In these cases, nearly all agents are group members. This seems to be not always the case in a classroom (e.g., according to Hallinan (1979) about 50% of adolescents on average are not part of a friendship clique). However, the role of friends is predominant during adolescence (Hartup, 1983), adolescents spend a lot of time with friends (Hartup & Stevens, 1997) and take part in a lot of activities with them (Mahoney, 2000). What is important is that the model is generally able to represent the formation of distinct friendship groups with different degrees of clustering. By doing so, it correctly simulates the general tendency of adolescents to build friendship groups that represent a certain variety of emerging friendship networks.

The results for the correlation between distance in the friendship network and the behavioral profile clearly indicate the rejection of the null hypothesis H0.2 that postulates no sufficient effect of correlation between behavioral attributes and distance in the social network. In about 90% of the cases the correlation is significantly different from 0 (for average risk behaviors as well as for average conventional behaviors). This can be interpreted as follows: Agents standing closer together in the network also tend to behave more similar and those with higher distance in the network seem to be more dissimilar. Therefore, homogeneity among friends and groups of friends within the network has emerged. However, a closer look at the results shows that especially for the cases of small clustering degree (about 1) the correlation became small (although still significantly different from 0 in most of the cases). In these cases, mostly one big homogenous group has emerged and the behavioral covariance became very small (in some cases even 0). The model encounters again the same problem: In some cases the groups are too homogeneous. In other words, in a number of simulations, all agents tend to build one group and behave in a similar way. Although adolescents seem to be pretty similar in their attitude and behaviors, in reality a very high level of homogeneity seems is very unlikely. To solve this problem and avoid this overclustering effect the parameter settings could be changed. Of additional interest are the cases that show a high degree of clustering, but at the same time a small correlation. These cases can be interpreted as an occurrence of mixed groups. In other words, the members show a composition of different behaviors. These groups are more heterogeneous. Although we assume homogeneity among friends for a majority of cases, it is also known that friendship can be based on complementarity (Aboud & Mendelson, 1996; Güroglu, val Lieshout, Haselager, & Scholte, 2007; Urberg, DeĐirmencioglu, & Tolson, 1998). We can conclude that the model also seems to be able to reveal cases of heterogeneous group building, though for most of the cases behavioral homogeneity arises. Therefore, the model represents empirical findings of homogeneity in a sufficient manner and additionally gives a reasonable amount of variance.

The third hypothesis ($H_{0,3}$) postulates that the model reveals differences between the initial and final decrease of the behavioral variance between the groups. The result indicates a rejection of the null hypothesis, since ΔSD was significantly different from 0. However, recall that the number of simulated cases is small (i.e., 100) and that more simulations need to be run to arrive at a better estimation of the confidence interval. A suggestion to improve the validity is to perform more model runs and to additionally inspect different parameter ranges.

In case of the last null hypotheses on influence and reinforcement (H0.4 and H0.5), the model results correspond with reinforcement in most of the cases (about 80% of all cases), and in about 30% of the model runs the results reveal at least one case of influence (or more). In short, both the null-hypothesis assumption that the model produces no cases of influence and the null-hypothesis assumption that the model will not represent reinforcement for the majority of cases must be rejected. We can conclude that most of the agents in the model are reinforced, which means that they adapt to each other by stabilizing their general behavior. At the beginning the agents already show a certain similarity with those agents they finally build a group with. For the influenced agents arises a somewhat different image: At the beginning of a simulation run they are actually more similar to other agents than those they finally end up with. In this case, the agents seem to be especially influenced and pulled into a group by more or less dissimilar agents.

In short, this chapter shows that is possible to combine results of existing empirical researchers to build a dynamic systems model of friendship interaction. We showed how to use the model as a digital laboratory to experimentally test hypotheses, to generate specific predictions and in the end compare the predictions with the results of the empirical findings. This approach can be successfully used to fully understand how properties of psychological phenomena change over time and under which conditions and rules the mechanisms of change take place.

CHAPTER 5

A LONGITUDINAL STUDY OF FRIENDSHIP INTERACTIONS AND RISK BEHAVIORS DURING ADOLESCENCE: BRIDGING EMPIRICAL AND SIMULATION RESULTS

INTRODUCTION

In the last two decades, researchers have demonstrated a strong connection between risk taking behaviors and membership of particular peer groups. Many psychological and social studies claim that peer group influence is the major cause of initiation of smoking and drinking (Dishion & Loeber, 1985; Elliott, Huizinga, & Ageton, 1985; Hawkins, Catalano, & Miller, 1992; Jessor, 1992; Schulenberg & Maggs, 1999; Wang, Fitzhugh, Westerfield & Eddie, 1995). Peers appear to be also related to the escalation of more serious problem behaviors such as delinquent behavior and violence (Dishion, Bullock, & Granic, 2002).

Although risk taking behaviors and affiliation with peers have received much attention from researchers, we still do not know enough about how these variables are associated. Some methodological and theoretical limitations, such as the widespread use of cross-sectional designs and the problematic nature of assessing friendship networks, lead researchers to overestimate the causal, i.e., uni-directional role of peer influence. However, two types of evidence suggest a pattern of symmetrical or mutual causality. First, friendships are determined in large part by behaviors (selection mechanisms) and secondly adolescents attribute their own behavior to friends (projection mechanism) (Bauman & Ennett, 1996). As these two authors pointed out, the assessment of selection effects requires specific designs and measures. Cross-sectional studies are highly limited in this respect. Even though cross-sectional studies can be informative, they can only find eventual statistical associations between risk behaviors and having friends across a sample. But they fall short in that they do not take into account the time evolution or process characteristics and they cannot describe how reciprocal influences occur in real time. Furthermore, cross-sectional studies rarely take into account the social network of the adolescents and confine themselves to describing the behavioral attitudes of the adolescents and do not include that of their friends.

Recently, the body of researches that includes longitudinal designs and the use of social network analysis has increased. By using these techniques researchers have discovered that not only influence but also selection processes play an important role in the development of similar behaviors among friends. By discovering the role of selection processes, the researchers have placed the emphasis on the active choice of the adolescents in selecting friends who have similar behaviors. Friendship is no longer the unique and independent cause of the behaviors; in fact, it is the pre-existing similarity that forms an important cause of the establishment of the friendship (see for a review: Arnett, 2007, Bauman & Ennett, 1996; Cohen 1977; Engels, 1998; Kandel, 1978).

We believe that only by taking into account the dynamic reciprocity between selection and influence processes the formation of similar behavior among adolescents can be fully explained. The main goal of the current chapter is to give a complexity-based view of the socialization process of adolescents and their friends by using a research design that takes into account both selection and influence processes. In this study we monitored the development of adolescents, focusing on their change in risk behaviors involvement and their change of the friendship relations. The study covers four measurement points during the course of one year. In order to assess both selection and influence processes we selected our sample before new friendships were formed, using the natural formation of new networks in schools, when children move to a new grade. In the Dutch educational system, the students who follow the VMBO curriculum (i.e., prevocational education) have to choose a new track between the second and the third grades. This means that during this transition, new groups are formed and the students meet new classmates. Our first measurement took place just before this transition. Phase transitions can be interesting moments to study because they are characterized by turbulence and instability (Granic, Dishion & Hollenstein, 2003; Thelen & Smith, 2004) and, therefore, can enhance the initiation of new behaviors. Take for example Julia. She is a 13 years old girl who has just finished her first two years of secondary education and is going to start her third year. Julia is a sportive girl, committed to her school, and she is mildly involved in risk behaviors. From time to time she smokes a cigarette and drinks some alcohol. During the first weeks of her third year of school, Julia meets Sarah who is also a sportive girl but is also interested in music, going out with friends, smokes cigarettes and drinks regularly alcohol. Sarah and Julia like each other and become friends. Going out with Sarah, Julia starts to know new people, enters in a new social world and makes contact with a new life style. After a few months of relationship the smoking and drinking behaviors of Julia have increased, reaching the level of her friend Sarah. Could we call the increase of Julia's risk behaviors a case of peer pressure? If we would only correlate Julia and Sarah behaviors the answer will be yes. However, if we go beyond the simple counting of the frequency of the behaviors of the two friends, the answer is no. By observing Julia's and Sara's behaviors before the relationship is started, we have noticed that they already have similar behavior prior to their friendship. Furthermore, they both like each other, probably because they share certain interests and behaviors. This example illustrates how important it is to include transition phases in research designs. By using them we can capture the behaviors and the inclinations of the individuals before changes may occur and, therefore, we can be more accurate in determining the relationship between the properties of the phenomena under study, and in particular the characteristics of the underlying processes.

1. The current study

Many studies have discovered that friends are similar regarding behaviors and attitudes (e.g., Ennett, Bauman, & Koch 1994; Kandel & Davies, 1991; Patterson & Dishion, 1985) and that this similarity increases over time, reaching its strongest point when stable friendship pairs have been formed (Berndt & Keefe, 1995; Kandel, 1978). However, only few studies have focused on understanding how similarity changes and develops over time. As regards the stabilization, researchers have found that in established and reciprocal friends the similarity is no longer subject to variation, since stable friends have already the same level of similar behaviors (Bot, Engels, Knibbe & Meeus, 2005). Furthermore, we have learned from the dynamic systems principles (van Geert, 1994, 2003) that psychological phenomena are rarely static, on the contrary they are often subject to variation and often change over time. More specifically, it can be shown that if two variables entertain a supportive dynamical relationship (as in the case of similarity among friends), their pattern of growth will go through a so called overshoot, after which they will show a decline that stabilizes at a higher level than the level they have started from (van Geert, 1994). Combining the findings of Bot *et al.*, (2005) and the dynamic systems principles of growth (van Geert, 1994; 2003), we believe that similarity will not remain stable over time and that after a certain level is achieved, similarity may go through a temporal decrease after which stabilization may set in. Our first goal is, therefore, to analyze the relation between friendship and behavioral similarity over time. Specifically, the first goal of the study is to verify whether adolescents and their friends share similar behaviors and whether similarity changes (i.e., increase and/or decrease) during the course of a year.

The second goal of this study is to verify whether friends share their similar behaviors previous to the establishment of their friendship (i.e., select each other on the basis of their pre-existing similarity). In the previous chapters, we proposed a sharp distinction between reinforcement and influence. Reinforcement occurs if two adolescents have similar levels of risk behaviors before they have a relationship (e.g., they both smoke); influence, instead, occurs if the adolescents do not display the same behavior prior of their friendship (only one friend smokes). This distinction can be empirically checked only if the pre-existing similarity among friends is measured.

The third goal of the study is the validation of the dynamic systems (DS) model described in chapters 3 and 4. The model, as well as the collected data, describes the dynamics of risk behaviors and friendship formation in adolescence. The model simulates how real-time selection and influence processes work together and relate to long-term processes, such as the emergence of friendship and homogeneity (i.e., similarity) of behaviors among friends. Furthermore, the model describes how behaviors change in relation to preferences, interactions, and evaluations of behaviors and properties (i.e., influence process) among friends. An important feature of the model is the ability to simulate predictions and generate results that are related to theoretical and empirical findings. These two aspects have been described in chapter 4. What we aim at in this chapter is the comparison of the model results with our empirical findings. We compared the empirical data and the model simulations in two main aspects, namely "similarity of behavior with friends" and "influence and reinforcement". In addition to the comparison, the model and the empirical results were also used for other aspects. For example, we used the empirical data as a starting point for the estimation of the parameters of the mathematical model. Lastly, the empirical data helped us in constructing a more realistic model, for instance, by including more "dramatic" events, such as the end of a friendship.

1.2 Questions and hypotheses

The first part of this study wished to answer the following questions: *Are friends more similar than non-friends? How does similarity change during the course of one year?* Concerning our first question we predicted that data will confirm a positive correlation between the behavioral attributes of the adolescents and the proximity with their friends in the social network, revealing that similarity is higher in friendship pairs than in non-friendship pairs. In relation to our second question, we expected that similarity will increase over time, and then will decrease before stabilizing at a higher level than the original starting position. We based this second hypothesis on the findings of Bot *et al.* (2005) and the dynamic systems principles of growth (van Geert, 1994; 2003).

The second part of this study focused on testing the hypothesis that friends share similar behavior before their friendship is formed (Bauman & Ennett, 1996; Cohen, 1977; Ennett & Bauman, 1994; Kandel, 1978; Kindermann, 2003). By assuming that similarity exists before the formation of the friendship and that in fact it is an important condition of the establishment of the friendship, we also assumed that future change in behaviors among friends is due to reinforcement and not to influence. Specifically in the second part of this study the following question will be investigated: *Do friends have similar behaviors before their friendship is formed?* We predicted that individuals who are not friends at t1 but become friends at t2 will have similar behaviors prior to their friendship and that, therefore, we will find many more cases of reinforcement than cases of influence.

1.3 Method

1.3.1 Participants and procedure

The adolescents who participated in this research project were recruited from a public secondary school in the Netherlands, located in the north of the country. Parents and participants were informed about the aims and procedure of the study. Only the students who received parental consent were included in our research. Our study started at the end of the second year of the secondary education and lasted for the entire third school year. We were interested in assessing changes in the adolescents' social life and for this reason we focused on a specific moment of the Dutch secondary education that includes a transition. In the Netherlands, this transition happens after the first two years, at the end of the Common Core Curriculum, when children choose specific tracks and move to new classroom groups. Therefore, we assessed the participants the first time after the end of the Common Core Curriculum. Participants were assessed via written questionnaires during regular school hours.

At t1 (June 2005) the sample was composed of 74 adolescents (25 male and 49 female) between 13 and 16 years old (M= 13.99; SD= 0.61) from different school types: Pre-university secondary education (in Dutch: *Voorbereidend Wetenschappelijk Onderwijs*, VWO), senior general secondary education (in Dutch: *Hoger Algemeen Voortgezet Onderwijs*, HAVO) and prevocational secondary education (in Dutch: *Voorbereidend Middelbaar Beroepsonderwijs*, VMBO).

When they were first assessed, 83% of the adolescents lived with both parents, 15% lived only with their mothers. The mean age of the fathers at the beginning of the research was 46.1 (SD= 5.9) and of the mothers 43.2 (SD= 4.9). The participants provided the information about their parents' education and actual occupation. From their reports, it appeared that the majority of the adolescents did not know what type of education their parents had (44% for fathers and 47% for mothers). The rest of the adolescents reported that 22% of the fathers and 10% of the mothers finished only a low level of secondary education, 32% of the fathers and 31% of the mothers had an intermediary level of secondary education, while 7% of the fathers and 11 % of the mothers had a high level of education. At the start of the research, 79 % of the fathers and 70% of the mothers had a job.

After the summer vacation, the school was visited again (t2 = October 2005, n = 61). Our third assessment took place three months later (t3 = January 2006, n = 54). The sample was again tested at the end of the third grade (t4 = June 2006, n = 56).

The following table provides an overview of the sample and the assessment procedure used for our research.

Table 1. *Overview of the sample and the assessments procedure*

Waves	Months	Class	n	Gender		Age	
				Female	Male	*M*	*SD*
t1	June 2005	II class	74	49	25	13.99	0.61
t1	October 2005	III class	61	38	23	14.31	0.53
t1	January 2005	III class	54	34	20	14.54	0.57
t1	June 2006	III class	56	17	23	14.93	0.57

Table 1 shows that between t1 and t2 we lost 13 students. This is connected to the school phase transition the students have between t1 and t2. For some students (n=7) this transition included not just the change of classes and classmates but also the moving into a different school building. These seven students were excluded from our sample. After t1, due to practical and organizational reasons (e.g., school time-table), we could include only the students who were following senior general secondary education (HAVO) and prevocational secondary education (VMBO). Therefore, the students who were following the pre-university secondary education VWO (n = 6) were also excluded from the other three assessments. The decrease in the number of students at t3 and t4 is, instead, caused by the absence of the students during the days of the assessment. In total, 52 individuals had a complete longitudinal profile (four longitudinal assessments). Only these 52 participants have been used in our analysis.

The data on all four measurement points were gathered by means of a questionnaire containing different sections and scales (e.g., socio-demographic variables, family variables, risk behaviors variables, psychological and social well being variables, friendships variables, activities variables and network mapping). In this study we will only focus on: Risk behaviors variables, friendship variables, activity variables and network mapping.

1.3.2 Measures

Risk behaviors: To measure the involvement in risk behaviors by the adolescents we used the scale “Antisocial and delinquent behaviors” of Deković (1999) and Noom, Deković and Meeus

(1996). The original scale was composed of 18 items (e.g., disregarding parent's prohibitions, drinking alcohol, carrying a weapon). The scale was meant to measure antisocial and delinquent behavior. The scale did not include a measure for evaluating a general level of substance use. Thus, we decided to add two items to the original scale: "drinking alcohol" and "smoking cigarettes".

The adolescents rated each item on a 5-point scale: 1 = never, 2 = once, 3 = two or three times, 4 = four to ten times, 5 = more than 10 times. At the first time point (June 2005), we asked the respondents to indicate how often they had performed each act during the last 12 months. During the second measurement point (October 2005), we asked to indicate in the same list how often they had done that activity over the last 4 months (June 2005), during the third measurement (January 2006) we asked to indicate in the same list how often they had done that activity over the last 3 months (October 2005) and during the last measurement (June 2006) we asked to indicate how often they had done it over the last 5 months. This procedure led to different time intervals during the measurements. The reason why we chose unequal time intervals was only related to practical issues. We had to organize the four measurements in connection with the school transition and the school time-schedule. Although not ideal, this choice did not cause any problem for our analyses, because our analyses did not include a comparison among absolute differences but only correlations at each measurement point.

As is relatively common in psychological research, the scale was graded on an ordinal level. In addition, the scale answers contain unequal quantities (i.e., distances between answers are different). We transformed the scale into an interval scale, that is, we changed the ordinal categories into real numbers and used those numbers to calculate three different types of ordinal codes (i.e., values): An average code, a minimum value code and a rank order code. We made this transformation in order to facilitate the mathematical calculations.

Table 2. *Overview of the different types of codes*

Original code	Average code	minimum values code	rank order code
1 = never	0.00	0.00	0.00
2 = once	1.00	1.00	1.00
3 = two or three times	2.50	2.00	2.00
4 = four or ten times	6.50	4.00	3.00
5 = more than 10 times	15.00	11.00	4.00

The correlations between the numerical codes of the frequency categories and the real averages were very high (average code = 0.86; minimum values code = 0.99 and rank order code =1.00), which warrants the conclusion that the use of the simpler numerical codes does not result in loss of relevant information. The analyses were, therefore, done with the rank order code.

The 18 items that composed the original scale were subjected to a factor analysis using the longitudinal data of the four measurement points (n = 245). Three subscales were distinguished. The first one (3 items, alpha = 0.39) referred to oppositional behaviors (e.g., disregarding parents prohibitions). The second scale (4 items, alpha = 0.77) referred to substance use such as alcohol and soft drugs. The last scale (10 items, alpha = 0.74) referred to aggressive behaviors and vandalism (e.g., beating someone, fighting, intentional fire setting)

Friendship: To measure the friendship ties of the adolescents we asked the adolescents to write down the name and the family name of their best friends. The participants could describe a maximum of five friends. In order to have a complete spectrum of the friendships of the participants, we used a strategy similar to Bot *et al.* (2005). Similar to this study, we did not limit the participants in nominating only friends of their classroom but allowed them to also nominate friends of other classes and friends outside their school. In order to understand if a nominated person was also a student of the same school or class, the participants were asked to indicate the friends' school and /or classroom of provenance. However, since we did not collect data of the friends outside the school, we could only compute the analysis among the friends of the school (both from inside or outside the same classroom of the participants).

Friendship in classroom: To measure the social network of the participants in the school context, we asked the participants to describe which classmates they liked most and which classmates they liked least. These data were used for the comparison of the empirical social network with the social network model (see page 105 of this chapter).

Activities after school and free time: To measure the activities of the adolescents we used the scale: "Activities after school and during free time" (Jessor, Donova, & Costa, 1992). The original scale was composed of 14 items. We used two of the 14 items: To study and to spend time at home. These items measured the conventional activities performed by the adolescents. The "Activities after school and during free time" scale ranged from 1 (1 = 0 hours) to 6 (8 = hours or more).

1.4 Strategy for the analyses

1.4.1 Question 1: Similarity among friendship pairs and non -friendship pairs

In order to determine the friendship ties among the adolescents, we checked whether the participants nominate one (or more) of their classmates or other students of their school as friend. Friends outside the school were excluded from the analysis. We performed the analysis to select the friendship pairs by means of a spreadsheet program, Excel. Using the program we could describe the social network of the students. By checking whether the nomination was mutual (i.e., both individuals had to nominate each other as friends), we obtained mutual friendship pairs at each measurement point. In order to determine the similarity among the friendship pairs we computed correlations (Pearson correlations) among their behavioral profiles at each time point, obtaining four correlation measures. By averaging the correlations among all the friendship couples we obtained four average scores of similarity among the friendship pairs. The behavioral profiles included three different types of risk behaviors and two different types of conventional behaviors. The original variables were normalized before the correlation was calculated.

Secondly, in order to verify whether friends were more similar than non-friends, we calculated the correlations of each participant with his/her non-friends at each time point. Also in this case, we averaged the correlations and we obtained four average scores of similarity among the non-friends. In order to test whether the difference among the friends and the non-friends was significant, we compared the average similarity of the friends with the average similarity of the non-friends. Due to the fact that our sample of friends was smaller compared with the non-friends sample, we tested the significant differences by means of a non-parametric permutation test (Monte Carlo simulation technique). This statistical technique is very well suited for dealing with small or unbalanced datasets. It determines the probability that an observed result is caused by chance alone by simulating that chance. For example, it makes a very large number of randomized distributions taken from the same underlying distribution and simply counts the number of times that the observed phenomena occur in the randomized distribution (Good, 1999; Manly, 1997; Todaman & Dugard, 2001).

1.4.2 Question 2: Change of similarity over time

In order to verify how similarity changes during the course of one year, we proceeded in the following way: Since we expected an increase in similarity we first checked the upward change of similarity (i.e., the difference between the second measurement and the first and between the third measurement and the first). Secondly because we also expected a decrease at the end, with between beginning and end an average increase, we checked the downward change of similarity (i.e., the difference between the second measurement and the fourth and third measurement and fourth).

Lastly, we calculated whether the difference among the measurements was significant by means of a non-parametric permutation test (Monte Carlo simulation technique, Good, 1999; Manly, 1997; Todaman & Dugard, 2001).

1.4.3 Question 3: Disentangling influence from reinforcement

In order to distinguish the selection process from the influence process it is necessary to capture the behaviors of friends before their friendship is already formed. Obviously, not all friendship pairs were included in the analysis because only a subsample was found to be non-friends at t1 (June 2005) but friends at t2 (October 2005), t3 (January 2006) and t4 (June 2006). After having chosen the couples of future friends, we checked whether friends were similar in their risk behaviors at t1 and at t2 by calculating the distance (absolute difference) between the average of their risk behavioral profiles at t1 and t2. We tested whether the difference was significant by means of a non-parametric permutation test (Monte Carlo simulation technique). Secondly, in order to check the presence of influence, we counted how many friendship couples we could find with no pre-existing similarity in risk behaviors.

1.5 Results

In total, we found 32 couples of friends at t1, 29 couples at t2, 36 couples at t3 and 27 couples at t4. Among these pairs, we found 14 couples were found to be non-friends at t1 but friends in the other measurements points.

1.5.1 Hypothesis 1: Similarity among friendship pairs and non-friendship pairs

Our first hypothesis predicted that similarity is higher in friendship pairs than in non-friendship pairs. We tested against the null hypothesis that friends and non-friends are not different other than by chance, i.e., that the values of friends and non-friends are in fact drawn from the same distribution. We tested this hypothesis with a Monte Carlo simulation analysis.

Table 3. *Similarity among friends and non-friends at 4 measurement points*

		t1	t1	t3	t4
Friendship pairs	*M*	0.47	0.62	0.64	0.53
	SD	0.39	0.44	0.41	0.45
	n	32	29	36	27
Non-friendship pairs	*M*	0.23	0.21	0.28	0.27
	SD	0.52	0.62	0.52	0.48
	n	1766*	1766*	1766*	1766*
p		0.003*	0*	0*	0.001*

* *Note*. This high number is due to the fact that the non-friendship pairs were calculated by taking any mathematically possible combination of all individuals who do not have a friendship. In order to avoid statistical artifacts resulting from this high number, we tested the difference by randomly sampling numbers of non-friendship pairs that are equal to the friendship pairs.

As you can see from table 3, on average friendship pairs are significantly more similar than non-friendship pairs. The result was found at each time point. Our first hypothesis is confirmed.

1.5.2 Hypothesis 2: Change of similarity over time

Our second hypothesis concerns the change over time of similarity among friends. We expected that the similarity will increase over time, and then will decrease before stabilizing at a higher level than the original starting position.

Figure 1 shows the mean across time of the four average correlation scores of similarity among friends and non-friends. As you can see from figure 1, the similarity among the friends increases between t1 and t2, it stabilizes between t2 and t3 and decreases between t3 and t4. However, the average score of t4 is higher (*M*=0.53) than the first measurement (*M*=0.47). This trend is not confirmed among the non-friendship pairs who show almost no difference between the 4 measurements (figure 1).

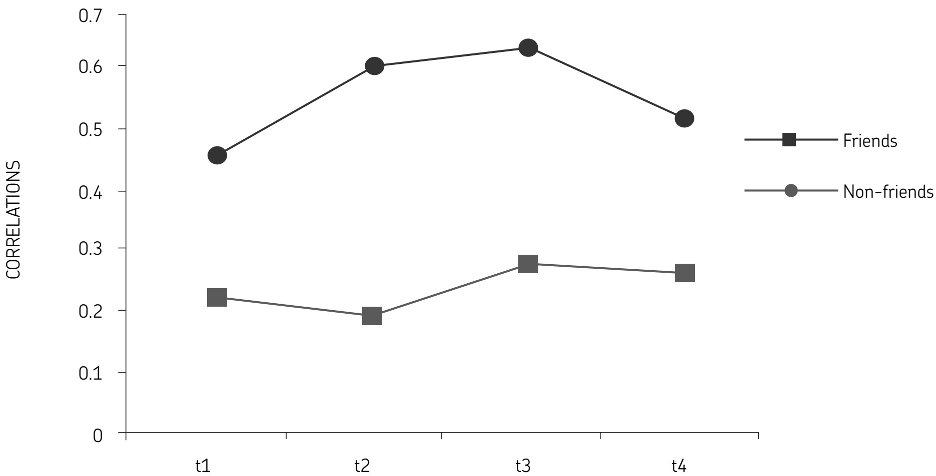

Figure 1. Change of similarity over time.

In a second phase of the analysis, we tested whether there was a significant increase and/or a significant decrease of similarity among the friends over the four measurement points. The analysis was not conducted among the non-friends. We tested against the null hypothesis that there is no difference among the friendship pairs over the four measurement points.

Table 4. *Significance of the difference between measurements*

	2nd-1st	3nd-1st	4th-2nd	4th-3nd
	up		down	
p	0.05	0.03	0.19	0.12

Table 4 shows the results of the analysis of the difference in significance between the measurements. We found a significant increase among the second and the first measurement and the third and the first measurement. Regarding the decrease of similarity, the analysis shows that there is about 12% chance that the similarity is at the same level of the previous measurements. Even if we did not find the standard 5% level of significance, we believe that our result is still meaningful. Given the fact that the data confirmed the prediction and that the alternative hypothesis, namely that there is no decrease, has a chance of only 12% of being correct, the odds are in favor of our hypothesis. We can conclude that our analysis shows that similarity significantly increases between the first and the third measurements. The last measurement is most likely a decrease after which stabilization can take place.

In sum, the results of the first group of analyses confirmed that behavioral similarity is a property that characterizes friends more than non-friends. Similarity is not a stable feature of friendship but changes during the course of time. Our analysis showed that during the course of a year similarity shows a reversed U shape: It peaks in the middle of the year and decreases at the end, stabilizing at a higher level than the original position. The results are coherent with the theory designed to formulate our conceptual and mathematical model (see also chapter 2 of this thesis).

1.6.3 Hypothesis 3: Influence or reinforcement?

Our third hypothesis predicted that friends select each other on the basis of their pre-existing similarity and that their future change of behaviors is due to reinforcement and not to influence. Specifically, we predicted that individuals who are not friends at t1 but become friends at t2 will have more similar behaviors at t1 than those who do not become friends. In order to check this hypothesis we proceeded in a few steps. In a first step, we tested against the null hypothesis that at t1 the individuals who are not friends at t1 but become friends at t2 are on average not more similar than can be expected on the basis of chance.

We tested this hypothesis with a Monte Carlo simulation analysis. The analysis revealed that on average the behaviors of non-friends at t1 was significantly similar, in comparison to chance (p = 0. 008). However, when we looked at the analysis of the single couples, we noticed that only couple 1, 7 and 10 showed a significant p-value (table 5).

Table 5. *Statistical significance of friends' similarity at t1*

COUPLE	*p*
1	0.06
2	0.77
3	0.85
4	0.14
5	0.37
6	0.41
7	0.08
8	0.55
9	0.80
10	0.06
11	0.34
12	0.15
13	0.40
14	0.57

In order to check whether the resulting p-value (i.e., smaller than 0,05) is mainly caused by only one member of the sample, we have calculated the p-value based on a Jackknife technique[1]. The jackknife test showed that none of the p-values rose above 0,05, thus showing that the p-value we found is not due to one single couple. However, we know from the individual p-values that the sample-based p-value is actually based on a few cases where the predicted effect is very clearly present. There are several cases where the effect is not present. However, this is not unique of our data set. Almost all sample-based statistics have good p-values only because there exists a subset in the sample that shows the intended effect very clearly (Manly, 1997). Almost no sample-based measure makes the effort to check individual p-values, and by not doing so, they actually conceal the fact that the finding is probably due to a subset of the sample, and not to every individual member of the sample. We can draw the sample-based conclusion that on average, i.e., across the sample, the 14 couples have selected each other on the basis of their pre-existing similarity, but also that pre-existing similarity is characteristic only of a subset of the sample.

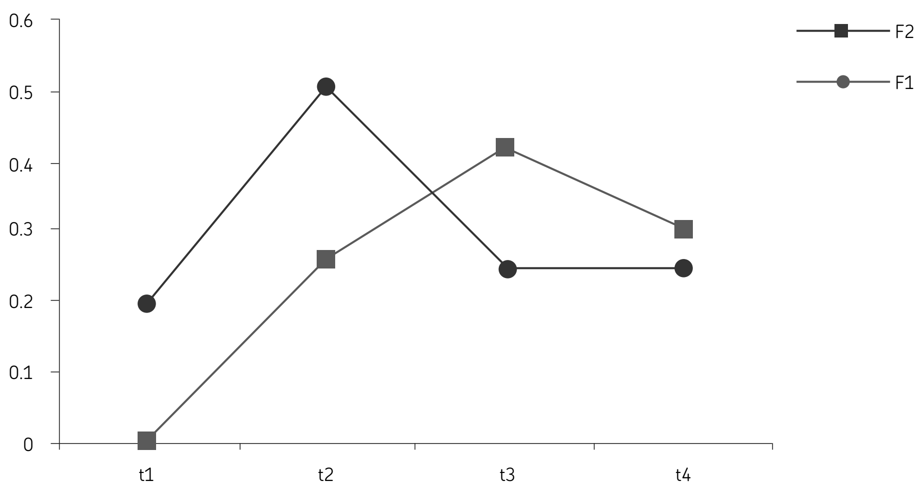

Figure 2. Influence over time (n=1).

[1] The jackknife technique is a statistical test that can be applied to check p-values based on small samples, e.g., a sample of only 14 couples. If you calculate a test statistic over a small sample (e.g., an average) and test the p-value, it is possible that the resulting p-value (i.e., smaller than 0.05) is mainly caused by only one member of the sample, for instance a couple with an extreme score. If we would leave that couple out of the sample, the p-value would no longer be significant, and it would be no longer recommended to draw conclusions from this sample if the p-value is based on only one member. If there are *n* members in the sample (in our case 14), the jackknife calculates a total of 14 averages, each based on n-1 (i.e., 13) cases. The test proceeds in this way: For each of the 14 averages, it leaves one member out of the set; such that average 1 is based on the set minus member 1, average 2 is based on the set minus member 2, and so forth. For each of these resulting test statistics, it calculates a p-value. If the p-value rises above 0.05 if you leave one member out, you know it is that member that causes the p-value to be below the 0.05 boundary of significance.

In a second step, we counted how many members of the 14 couples displayed no risk behaviors at t1 but showed the presence of risk behaviors in the successive measurements, indicating that influence occurred. As we predicted, we found more cases of reinforcement than influence; in fact, we found only 1 case of influence and 13 cases of reinforcement. Figure 2 shows the only case of influence we found in our sample. This figure shows the case of two friends: F1[2] and F2.
The figure shows that F1 is already involved in risk behavior at t1. F2 shows no risk behaviors at t1 (when he was not yet friends with F2). At t2, the two adolescents had become friends. Interestingly, at t2 F1 displayed more risk behaviors than F2 but at t3 we found a reversed situation: F1 decreased his risk behaviors, while F2 increased them. At t4 the behaviors of the two friends seem to reach a similar level. This example shows that the influence/reinforcement processes can proceed in two ways: They can make a friend increase his involvement in risk behaviors but they can also make a friend decrease his risk behaviors.

In sum, we found 14 couples who were not friends at t1 but had become friends in the successive measurements. Among these couples, the majority was already involved in risk behaviors before the friendship was formed. Only one couple was found having a different level of risk behaviors at t1. Following our conceptualization we claimed that this is a case of influence, while we named the other cases reinforcement. In general, our analysis confirmed that in the majority of the cases individuals select each other on the basis of their pre-existing similarity and that their future change is due to reinforcement more than to influence.

2. The empirical validation of a dynamic systems model of friendship interactions and risk behaviors during adolescence

In chapter 3 and 4 we presented a dynamic systems model that focuses on explaining how friendship relations emerge in the course of time among adolescents and on understanding how friends increase or decrease their similarity in behaviors. We first, theoretically and mathematically, described the properties of the model and the rules that make these properties change over time (chapters 2 and 3). Secondly, we showed how the model works and which behaviors it is able to generate (chapter 4). The model is based on theoretical and empirical findings drawn from literature in the area of adolescents' development and social network studies. On the basis of the literature findings, we formulated five model hypotheses, three of which are related to the concept of similarity (or also called: Homogeneity) and two of which are related to the concept of influence and reinforcement. The five hypotheses of the model can be summarized under one main assumption that makes the following statements. Adolescents select each other and become friends on the basis of similar attitudes and behaviors (e.g., musical preference, smoking). When interacting with each other they co-adopt their behavioral profiles so that their behavioral profiles become increasingly homogenous. The change (increase or decrease of the

[2] The label F1 and F2 were arbitrarily chosen

behaviors they could have before the friendship) occurs by means of repeated positive evaluations. Since we did not find much information about change in similarity over the course of time in the studies we reviewed, the model does not explicitly take into account the decrease of similarity among friends. However, in view of the results of the empirical study, we should assume that not only agents who do not like each other decrease their similarity but also agents who like each other can in the course of the time stabilize their similarity level and eventually even decrease their similarity. Since the model has been developed before the final results of the empirical study were known, this hypothesis is not included in the model.

The model distinguished two main forms of imitation mechanisms: Influence and reinforcement. The five hypotheses of the model have been qualitatively validated in chapter 4. All five hypotheses were confirmed by the qualitative validation. In the following sections we are going to compare each of the five model hypotheses and results with the hypotheses and the results of the empirical data.

2.1 The Homogeneity hypotheses

The first three hypotheses of the model deal with the concept of friendship and how friends change their similarity of behaviors over time.

2.1.1 Groups emerge

The model is primarily an interaction model that tries to simulate the formation of friendships in a school classroom. The first achievement of the model is to show that the agents will tend to form groups and how many of such groups will emerge. The results of the model showed that on average two dense clusters (or friendship groups) have emerged, even if in a relatively small number of cases (circa 30%), the model shows high connectivity between the agents.

In order to compare the results of the model with the empirical data, we described the social network of the four classroom groups that have participated in our study (n = 52). We described the network of the participants by asking them to describe which classmates they liked most and which classmate they liked least. Then we compared the network of the last measurement point (June 2006) with the network that the model generates at 2000 simulation steps (see page 72 of chapter 4). The following figures (3, 4, 5, and 6) show the social networks of the 4 classes (3 a,b,c,d at t 4). The ties between the persons mean that they like each other. If there is no tie between two persons this means that they dislike each other or have a neutral relationship. The figures show that in each class at least one network of friendship emerges. However, each class seems to display a different pattern of relationships or, in other words, the network is different in each class. In class 3a (figure 3) we can observe that three groups emerge: group 1 (TS, AF, CB, AN, LVG); group 2 (MK, TN, MW, MS, MB); group 3 (VM, LVG, JM). Three members in the groups (AN, CB, LVG) have a function as liaisons connecting the three groups with each other. In this class three classmates (CB2, HN, VJ) do not have any preference for other classmates. In class 3b (figure 4), students form two main groups: group 1 (JR, HN, YT, DM, JJ, WE) and group 2 (DM, JJ, JG, FN, JF, RW) with two members that function as liaisons (DM and JJ). There is also an isolate (DF) and a classmate who is related to one of the members of group 2 (KS), but not to the rest of the group. Class 3c (figure 5) displays a totally different network. There is a major group composed by five members: Four of them are related to each other (JB, LF, RB and CP); while one of them (GK) is only related to other two members (LF and JB).We can also observe the presence of a dyad (JKN and MN). Remarkably, six members of the class do not have any preference for other classmates (JS, JK, LZ, SB, TH, and TL). In class 3d (figure 6), we can see that there are two main groups: group 1 (1EK, LK,TVL, JV,HK) and group 2 (JV2, JS, SB, NN, EK and DB). The two groups are then connected with each other by four members (EK with JV2) and (HK with EK). In this class, all the individuals are integrated in the network, there are none isolated.

In summary, the empirical data showed that in each class at least between 1 to 3 groups of friends emerge. We also noticed the presence of classmates that function as liaison and classmates who have no preference for other classmates (i.e., isolates). However, the four classes displayed different types of network indicating that there is variation in the way classmates build up relationships with other classmates. Even if the model produces a clearer social network structure compared to the empirical data (it clearly shows the presence of two main groups), it is also able to reproduce the variation that we found in the empirical data (it shows the presence of one liaison and two agents with only few connections (see page 72 of chapter 4). For the purpose of this comparison, we can conclude that both model and empirical data are qualitatively similar in that they show the formation of a small number of groups of friends, including few cases of liaison and isolates.

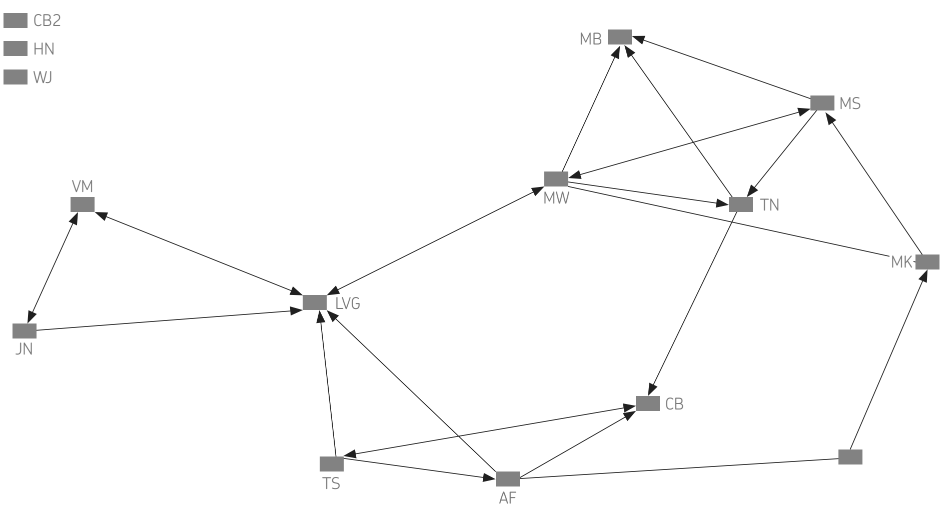

Figure 3. Friendship network classroom 3a June 2006.

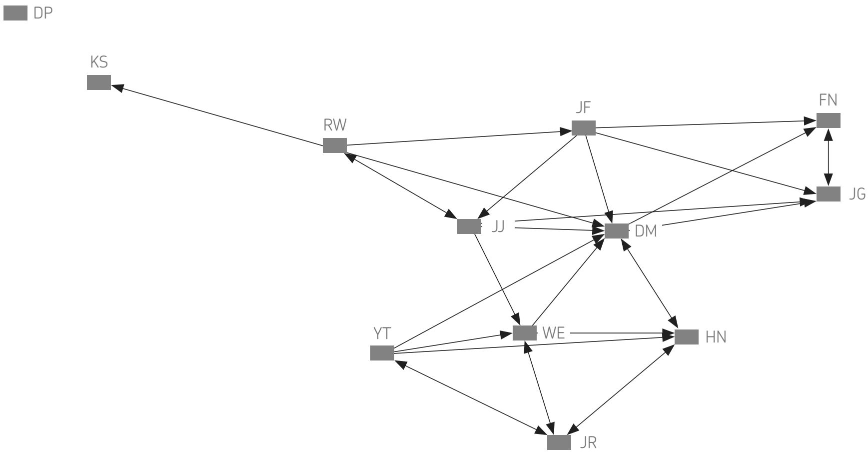

Figure 4. Friendship network classroom 3b June 2006.

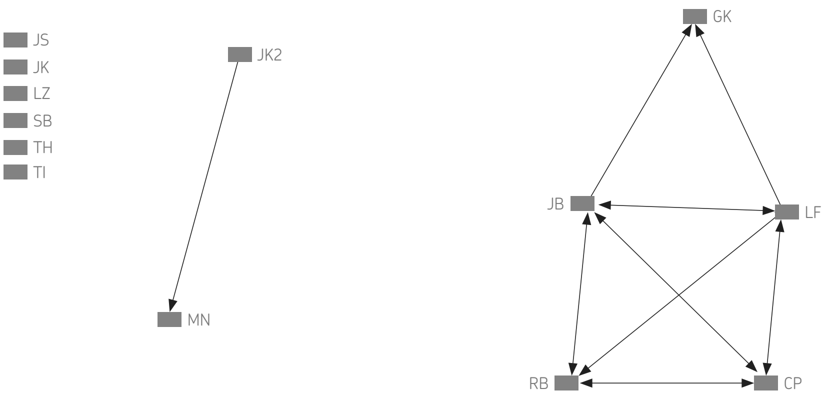

Figure 5. Friendship network classroom 3b June 2006.

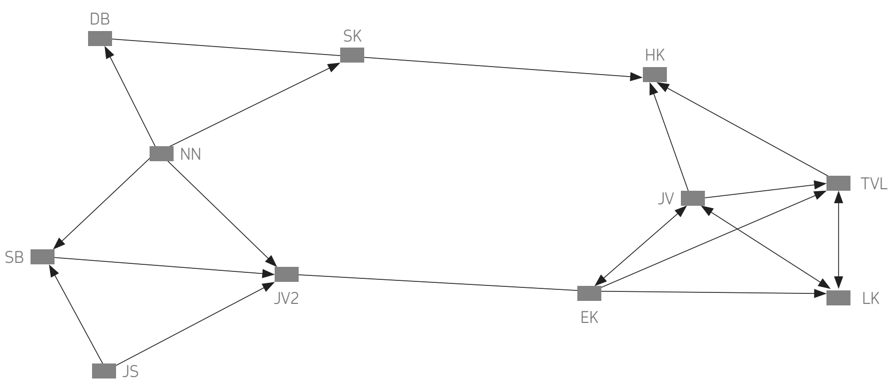

Figure 6. Friendship network classroom 3d June 2006.

2.1.2 Similarity

When we were building the model, one of our main concerns was to verify the similarity hypothesis. The model is centered on this hypothesis and it was very important that the model was able to reproduce it. After having checked if there were groups, our second goal was to understand if the groups of agents standing closer together (i.e., friends) were more similar than distant agents. In other words, can the model simulate that similar agents will tend to cluster together and non-similar agents will be positioned at a distance from these groups? In line with this question, we formulated the second model hypothesis as follows: "*The model reveals a relationship between the behavioral attributes and the distance between friends in the social network*". By distance we mean the strength of the friendship/relationship: The weaker the friendships ties, the higher the distance. The results of the model showed that agents that are located closely to each other in the network also tend to be more similar, while those standing less close seem to be more dissimilar. We could clearly observe that homogeneity emerges among friends and groups of friends within the network. However, in some cases the groups generated by the model are too homogeneous in comparison to what we can expect from real adolescents. Variation is more likely to occur in complex systems as human beings than in simple systems as a toy-world model.

As in the model, our main empirical concern was to confirm the similarity hypothesis. Our first hypothesis predicted that similarity is higher in friendship pairs than in non-friendship pairs. Our results showed that on average friendship pairs are significantly more similar than non-friendship pairs.

We can conclude that the model is coherent with the results of the empirical data. Both the model and the empirical data clearly show that in order to become friends a certain level of similarity facilitates the formation of a friendship relationship.

2.1.3 Similarity over time

The model is an iterative model with the advantage that it can simulate how properties change over time. Similarity is not a static concept and in order to understand it, it is crucial to predict it under the time-profile. The model should, therefore, be able to answer the following question: Does similarity change in the course of time? The third model hypothesis predicts that agents change or adopt their behavior faster in the beginning than at the end of the simulation. Specifically, it is formulated as follows: "*The model reveals a difference between the initial and final decrease of behavioral variance within the groups*".

The results of the model indicate a difference between the initial and final decrease of behavioral variance within the group. We could conclude that the agents change their behaviors more at the beginning (e.g., becoming more similar) of the simulation than at the end.

We expected that the similarity will change over time in the empirical data. Specifically, we hypothesized that similarity will increase and then will show a decrease and eventually a final stabilization at a higher level than the original starting position. Our empirical results were consistent with the predicted trend. We can conclude that both the model and the empirical data show that similarity is more prominent at the beginning of the relationship. The empirical data confirmed that similarity among friends can decrease over the course of time. However, the model does not provide any evidence of the decrease of the similarity. The next version of the dynamic simulation model should be changed in such a way that the final decrease of similarity spontaneously emerges on the basis of the same mechanisms that explain why it increases in the first place.

2.2 Influence and reinforcement

An important feature of a simulation model is the ability to show how mechanisms (in our case the influence mechanism) work over the course of time. Often, researchers have focused on studying the concept of influence but they have failed in their attempt to discover how it works, first because they fail to make a clear operationalization of the concept, secondly because they do not use the right tools to analyze it (for a complete argumentation of this issue, see page 32 of chapter 2). For this reason, researchers only seldom explain what they exactly mean by influence and what exactly happens when adolescents meet and influence each other. The advantage to work with a model is that it forces the researcher to think about the properties and rules that guide the mechanisms under study. Furthermore, a model can be manipulated and can be used to check which properties (and their level) and which rules fit better with the theoretical findings. By using the model we were forced to make a clear operationalization of the concept of influence and reinforcement (see page 95 of this chapter). After having operationalized the concepts, we formulated the following hypothesis: “*The model provides very few cases of influence and will represent reinforcement for a majority of cases*”. We found results that indicate reinforcement for most of the cases (about 80% of all cases), and in about 30% of the model runs the results reveal at least one case of influence (or more). We can conclude that most of the agents in the model are reinforced, which means that they adapt to each other by stabilizing their general behavior. At the beginning the agents already show a certain similarity with those agents they finally build a group with. For the influenced agents emerges a somewhat different picture: At the beginning of a simulation run they are actually more similar to other agents than those they finally end up with. Therefore, they seem to be especially influenced and pulled into a group by more or less dissimilar agents.

As in the model, our third hypothesis predicted that friends select each other on the basis of their pre-existing similarity and that more cases of reinforcement than influence will appear. Specifically, we predicted that individuals who are not friends at t1 but become friends at t2 will have similar behaviors at t1. The analysis revealed that on average the behaviors of non-friends at t1 were significantly more similar than could be expected on the basis of chance. This finding is coherent with the model assumption and with the theories we used to conceptualize our model. However, in the beginning some future friends were not more similar than any arbitrary pair of adolescents that did not become friends later on. This means that a high level of similarity is not a necessary precondition for becoming friends, although higher levels of similarities certainly facilitate friendship formation. In addition, we can conclude that the change in behaviors is due more to reinforcement than influence. However, whereas the model is able to clearly show which agents are influenced or reinforced and with whom they interact in the network, the empirical data do not offer such detailed spectrum of information.

Summarizing, in this section we compared the five model hypotheses and the model results with the empirical data. The similarity/homogeneity hypotheses of the model were coherent with the findings of the empirical data. What strongly emerged from both the model and the data is that similarity seems to play a facilitating role in the formation of friendship among adolescents. Both the agents and the adolescents displayed similar behaviors with their friends and select each other on the basis of this similarity. In the empirical data we found that for a sub-sample of adolescents the level of their risk behaviors is similar prior to the starting of their friendship. We can conclude that both the model and the empirical data confirm the importance of similarity in the formation of friendships. A less powerful conclusion can be made regarding the influence/reinforcement hypothesis. In relation with this aspect, in the empirical data we could only find 14 couples with pre-existing similarity.

3. Summary and conclusion

The first aim of this study was to investigate the relationship between adolescents' behaviors and their friends' behaviors by focusing, first, on understanding whether behavioral similarity is a property that characterizes friends more than non-friends and, second, by measuring similarity over time and among friendship pairs. Our results showed that on average similarity is higher among friendship couples than in non-friendship couples. Furthermore, our results indicate that during the course of a year similarity shows a reversed U shape: It peaks in the middle of the year and decreases at the end, stabilizing at a higher level of the original position. Thus, similarity of behaviors seems to characterize more the first phase of friendships than the later stages. But why is similarity more important at the beginning than at the end of a relationship? Bot *et al.* (2005) argued that in established and reciprocal friends the similarity is no longer subject to variation, since stable friends have already the same level of similar behaviors. Our results show that the level of similarity over time seems to achieve stabilization at a higher level than the original, but lower than the maximum level. A possible explanation of this finding is that at the beginning of a relationship, people need to do activities together in order to feel close and accepted. Thus, superficial characteristics such as sharing similar behaviors are important in order to start and develop a relationship. In the course of time, individuals increase their knowledge about each other and become closer. Therefore, in later stages of a friendship other criteria may become more relevant than sharing similar behaviors. This finding is also consistent with general dynamic growth principles (van Geert, 1994; 1996).

The results of this study were also used to validate the mathematical model we have described in chapter 3 and 4 of this dissertation. One of the most important assumptions of the model concerned the similarity hypothesis. The model simulation clearly shows that agents standing closer together (e.g., friends) are more similar than agents at a greater distance from each other. The similarity hypothesis was also confirmed in the model simulation.

The second goal of the research was to verify whether friends select each other on the basis of pre-existing similarity and whether their future change in behaviors was due to influence or reinforcement. In this research, we used a transition phase in order to capture the behavioral profiles of adolescence before they were becoming friends. With the help of this strategy and the model simulation we provided a new perspective on the way adolescents influence each other. Our perspective is centered on two main aspects, first, a clear differentiation between influence and reinforcement and second, the active role of the adolescents in selecting their friends. This study aimed to verify whether our new perspective was supported by the empirical findings. Among our participants, we found a sub-sample of students who were non-friends at t1 but became friends at t2. The results show that on average they already shared the same types of risk behaviors at t1 (when they were no friends) and at t2 (when they had become friends). We also found one couple that did not present pre-existing similarity in terms of risk behavior, and therefore we claimed that this couple is an example of what we call "influence process". Similar findings have also been found in the model simulation. Both the empirical study and the model confirm that only considering influence mechanisms is no longer sufficient for explaining the dynamics of peer group situation.

Our study has a number of limitations. First of all, there were in total 54 adolescents participants. Among these we found 14 couples of friends who were not friends at t1 (they had become friend at t2) and one couple who showed a case of influence. Our sample is relatively small and thus conclusions must be drawn with great caution. Therefore, in order to generalize the findings of our study, it is necessary to collect more empirical data. Specifically, we believe that researchers should make more effort in collecting data about the pre-existing similarity among friends and/or data that include multiple measurement points.

Another important limitation is related to the fact that our study has only incorporated friendship relations inside the school context but it misses the detailed information of the external social network e.g., parents, other relatives, outside school friends. In short, we did not check for external influences. Therefore, we can only speculate that the adolescents' change in behaviors is due to the reinforcement they have encountered from the friends who also participated in this research and not to other external factors. In this respect, qualitative studies found that the family is also an important context for the initial risk behaviors like smoking experiences. Parents, but also cousins, uncles and grandparents are often depicted in starting-to-smoke stories. For example, adolescents describe that they start smoking because parents ask them to light a cigarette or to buy a package (Alexander, Allen, Crawford, & Mccormick, 1999).

In conclusion, we believe that the use of social network data, longitudinal designs and mathematical dynamic modeling can be very useful in making a further step in the understanding of how the properties of social interactions change over time and form stable form of behaviors. This study shows that it is possible to use a time serial approach to verify the predictions made by the dynamic model.

CHAPTER 6

SUMMARY AND GENERAL DISCUSSION

INTRODUCTION

The main aim of the present study was to build a theoretical and mathematical model of social interaction and risk behaviors during adolescence based on the perspective of complex dynamic systems.

The theoretical and empirical work on influence and selection has been a main source of inspiration for this thesis. Although we were happy with the extensive literature available on this topic, we could hardly find a general theory that explains how influence and selection change over time. In order to fill this gap, we used the already existing literature and empirical findings to build a conceptual and mathematical framework about how social influence and selection of friends work and develop over time. Our main contribution to the previous literature was the extension of the existing theories to a time-frame (dynamical) approach. Having this aim in mind naturally brought us to choose the dynamic systems approach as the main theoretical and empirical guide of this thesis. This approach is especially useful for describing developmental processes, for studying developmental processes on different time scales (i.e., real and developmental time) and most of all, for constructing theories about these processes. An important advantage of using the dynamic systems approach is that it forced us to develop a clear idea of the nature of the properties of influence and selection and more particularly of the nature of the function that transforms these phenomena (van Geert & Steenbeek, 2005). Thus, we had to formulate our theory of change in a precise and detailed manner by, first, identifying the basic characteristics of the processes we wished to model and, second, by identifying the dynamic relationship among the properties and their dynamic nature. In other words, we had to formulate rules (i.e., dynamic laws) that make the properties change over time. The starting point of our research has been the formulation of our main (dynamical) questions: *How do friends promote changes in adolescents' attitudes during short-term interactions and over time co-adapt their own behaviors to that of their friend?*

To answer the previous questions we applied a multi-level approach (in the non-statistical sense of the word) that includes three main steps:

1. The formulation of a conceptual framework
2. The translation of the theory into a mathematical model of a dynamic system
3. The validation of the theory with empirical data

In this concluding chapter we will first summarize the findings of the three main parts that compose the present thesis. We will conclude the chapter by describing the strengths and limitations of the study and the empirical applications of our results.

1. The conceptual framework

We presented the conceptual framework in Chapter 2. We started this chapter by asking ourselves the following questions. How does the literature explain the formation of homogenous behaviors among adolescent friends? What are the conceptual properties of influence and selection mechanisms? Can we dynamically reformulate these properties? Although we consulted a considerable amount of literature, our conceptual framework is mostly inspired by the pioneering works on homogeneity of Bauman and Ennett (1996), Cohen (1977), and Kandel (1978). These authors postulate that selection plays a big role in creating similar risk behaviors among friends. Once individuals have selected each other and have become friends they may reinforce common behavior and in that sense operate as a force of reciprocal influence. We decomposed this assumption in ten sub-properties: Risk and conventional behaviors, perceived behavior, similarity, perceived similarity, preference, mutuality, interaction, interaction value, popularity, and evaluation. In our view these properties represent the minimum number of properties that by interacting on different time scales may generate behavioral similarity among friends. Chapter 2 presented the theoretical description of the ten properties followed by an explanation of how we implemented each property in the model.

We concluded the chapter by proposing a conceptual framework that focuses on explaining the relationships between friendship and risk behaviors during adolescence. Specifically, the framework aims to explain how the short-and long-term properties of selection and influence work together to generate different and stable developmental outcomes, such as friendship and homogeneity of risk behaviors. We can summarize our conceptual framework as follows: Adolescents become friends on the basis of their behavioral profile (i.e., similarity), preference and/or popularity, and because of mutual influence or reinforcement they co-adapt their behavioral profile in such a way that their behavioral profile, if it is positively evaluated, becomes more homogeneous. If adolescents evaluate each other negatively, the interaction is likely to stop. Our conceptual framework proposes a clear distinction between influence and reinforcement. Influence occurs if an adolescent adopts a new type of behavior (e.g., starts smoking) because a friend is already displaying that behavior. Reinforcement, instead, takes place if both friends are already involved in some risk behaviors and increase the behaviors due to the interactions with the friend.

In our view, our framework is innovative in three main aspects. First of all, our framework heavily relies on the notion of time. More precisely, it distinguishes between what happens in the short-term interactions (the now) when two adolescents meet, exchange knowledge and evaluate each other on the one hand, and the long-term effects of these interactions (after a year), for example the increase in similarity or the formation or dissolution of a friendship on the other hand. Secondly, the framework mathematically and theoretically distinguishes the notion of reinforcement from the one of influence. This is a clear example of how the use of modeling in psychological research can help the researcher to think about new hypotheses and relations among phenomena. Third, our framework indicates the role of evaluation as a motor of change. By stressing the role of evaluation as the property that may let adolescents change their behaviors, we wished to emphasize the active role the adolescents have in selecting, maintaining and/or dissolving their friendship relations. In our conceptualization, adolescents are no longer seen as passive receptors of influence, first because they choose their friends on the basis of their perceived similarity, and second because they actively express a preference towards their friends and in turn express an evaluation. We suggest that further researchers should devote more time and effort to the understanding of the role of evaluation in friendship, especially of how evaluation works and changes over time.

2. The mathematical model

2.1 The description of the mathematical model

In chapter 3, we presented the mathematical version of the previous framework i.e., a mathematical model of friendship and risk behaviors during adolescence. We translated the ten properties and the relations among them in matrices and in mathematical formula respectively. Our mathematical model describes the behavior of 20 agents. We chose 20 agents because this number represents the average school classroom size. The agents are a simple representation of real adolescents (thus you could also call them "simulated adolescents"), they have a name and a value on each of the ten properties formerly described. The agents' values of the properties resemble typical adolescent values. Comparable to the real adolescent population, some agents are more involved in risk behaviors, are more popular or express a specific preference to another agent and so forth. Most important in our model, the values change over time on the basis of simple theoretical and mathematical rules governing the interactions between properties within and between individuals.

Technically speaking, the present model is a combination of a discrete dynamical systems and an agent based model. The model consists of a number of coupled equations and decision rules that work in an iterative way. The model is implemented in the form of a Visual Basic (VB) for Applications model and runs in Microsoft Excel. A simple but in our view also innovative idea of the model is that you can use a very common and relatively easy program such as Microsoft Excel to translate theoretical properties into mathematical matrices and iterative operations on those matrices. The iterative operations simulate the temporal processes of the phenomena under study, in our case friendship and risk behaviors during adolescence.

A matrix is very similar to a table: Vertically it is composed by a series of names and horizontally by a series of values. However, very differently from a table our matrices are time-indexed (i.e., there is a matrix at t1, t+ Δt, t+ 2Δt, t+ 3Δt etc.) and are characterized by an iterative process. The iterative process implies that all matrices are updated at each model step. In other words, the agents start with a particular value but at each time step of the model the values of the properties are newly calculated based on the limited set of mathematical operations that represent the basic theoretical mechanisms from the developmental model.

Next to the iterative process, another innovative aspect of the model is that it distinguishes between short-term properties and long-term properties. The first characterize the real-time interactions among the agents, for instance what happens when agents "meet" for the first time and start to interact with each other in their environment (i.e., a simulated classroom), or what happens during a concrete interaction among the friends of the agents. Our model is composed of the following short-term properties: Behavior, perceived behavior, similarity, perceived similarity, preference, popularity, mutuality, interaction, interaction value, and evaluation. The choice of these short-term properties is based on a literature review. The long-term properties arise from a series of interactions of the short-term properties. In the current version of the model, we focused on two main outcomes: Friendship and homogeneity in behaviors. However, the model is not limited to generating only these two long-term properties and is in principle able to generate more outcomes.

Another innovative aspect of the model is that the rules that govern the model (i.e., dynamical laws) are fixed but the application of these fixed rules leads to updates of the variables at each model step, which corresponds to changes in the variables over time. This means that the way of calculating for example the risk behaviors does not change during the simulation. However, the value for the risk behaviors is updated at each model step and it adapts to the currently given situation. As we said earlier, our rules of change are mainly based on theoretical findings and empirical researches of Bauman and Ennet, (1996), Cohen, (1977), and Kandel, (1978). We formulated our rules first as in the form of a conceptual expression. For example, the "*rule of behavior*" states: *The change at time T +1 of an agent's behavior is proportional to the difference between the agents' behavior and the behavior of an agent with whom he had an interaction; the change represented by the parameter c depends on the evaluation of the interaction* (For a complete overview of the rules, see page 58 of chapter 3). Successively, each conceptual rule has been translated into a mathematical equation that looks, for example, as follows:

Rules of behavior

$B^{1}_{t+1} = B^{i}_{i} + (B^{j}_{i} - B^{i}_{i}) \times c$

B^{1}_{t+1} = Behavior of Agent i at time step t+1

B^{j}_{i} = Behavior of Agent j at time step t

c = Change factor (depending on evaluation)

The conceptual phrasing of the rule is often based on an "*if-then*" statement but the phrasing of the rule itself takes the form of a *difference equation*, i.e., an equation describing the stepwise change in a variable on the basis of the values of other variables.

One special feature of the model and also its main strength is that, different from standard statistical techniques, the model does not attempt to predict different values of a factor (e.g., the amount of risk behaviors of an adolescent) from values of other factors (e.g., Homogeneity among his friends). On the contrary, the model tries to use dynamical rules and non-linear interactions among its properties in order to explain how homogeneity emerges and develops in the course of time. In short, the model aims to provide an explanation of a mechanism of change.

Although we believe that our model presents a series of interesting innovations, it is not the only network model of social relationships. In the literature we can find a number of very interesting dynamic models, for example the *stochastic actor-oriented* models (Snijders, van de Bunt, & Steglich, 2010). These models are based on longitudinal network analysis and on modeling dynamics of networks. In other words, the main goal of these models is to make statistical inferences about predictors of changes in network ties and individual behaviors on the basis of observed longitudinal data. All of these models are continuous-time Markov Chain Monte Carlo models. These models can simultaneously represent different network effects, such as transitivity, similarity and assortative matching (i.e., the choice of network ties based on similarity of network position) (Snijders, *et al.*, 2010). The central units of these models are the actors that are represented by nodes in the network. The relationships of the actors are represented by the ties between the nodes. The ties between actors change over time and the actors play a crucial role in changing their ties to other actors. The changes of the ties are driven by a so-called objective function, which evaluates the actions of the actors and determines probabilistically the tie changes made by the actors (Snijders, *et al.*, 2010; Steglich, Snijders, & Pearson, 2010). The changes in behavior depend on an objective function similar to the *objective function* for the network changes. The coevolution model, the state space of which consists not only of the network but also of changing individual characteristics (behavior, representation of development, etc.) allows actor-oriented models to disentangle selection from influence effects (Burk, Steglich, &Snijders, 2007; Kiuru, Burk, Laursen, Salmela-Aro&Nurmi, 2010; Knecht, 2008).

Actor-oriented models have a number of features similar with our model. Specifically, both models are dynamical, apply similar techniques such as iteration, include stochastic effects, are driven by rules (functions) of change, and model behavioral change and networks (in our case mostly friendship relations).

However, actor models differ from our model in several respects. The central units in our model are the individual autonomous agents. Autonomous agents depend on each other for their functioning, however they have also specific internal properties (e.g., preference), they are able to perform actions (e.g., they interact), and have intentions (e.g., evaluation). Our agents base their actions on their intentions and internal properties and finally evaluate whether a particular action complies with their intentions (e.g., evaluation). Some of the agents' properties are represented in the form of different initial states (e.g. perceived behavior and perceived similarity). This means that these internal properties will change in the course of an interaction process. For instance, at the beginning of the agents' interaction these two properties are less accurate than in later stages of the interaction. We made this distinction to represent the fact that individuals gain knowledge about each other over time (i.e., we know more about the others over time).

Actor-oriented models and our model also differ in relation to their final aims. The emphasis of the actor-oriented models lies on the *network* structure of the interactions and on the structure of the relationships that emerge in such a network (Snijders, *et al.*, 2010). In our model, the network structure of interactions is less important than what these interactions do with our agents in the short-term timeframe of an actual interaction and in the long-term time frame of emerging friendships and changing internal behavioral properties of the agents. Our main aim is to simulate the qualitative unfolding of properties and processes; therefore the typical numbers of agents considered in our model is smaller than in actor oriented models.

To conclude, we can claim that our model is more like a psychological type of simulation model, while actor models are more sociological type of models, perfect for simulating social network dynamics. In the future, it could be interesting to incorporate some of the actor oriented model features or to test some of our hypotheses with the actor-oriented model.

2.2 The results of the mathematical model[1]

In chapter 4 we presented the output of the model. As we previously showed, our model is an iterative model that over time generates different outputs. To check whether the model is sufficiently valid, we postulated and tested five hypotheses. Three were related to the concept of homogeneity and two to the concept of influence and reinforcement. The results of the analyses showed that the model is able to represent the emergence of friendship groups and the increase in similarity among the friends. Specifically, the model is showing how similarity arises by making agents move towards each other in the mathematical space of properties, and how a decrease in similarity arises by making agents move away from each other. The model is also showing that there is more change in behavioral similarity at the beginning than at the end of the simulation. The last results of the analysis showed that reinforcement is more likely to occur than influence. In short, all our hypotheses were confirmed by the model simulations.

Overall, the results indicate that the model works and is stable enough to generate results comparable to the literature findings. Specifically, the model is able to generate major qualitative empirical properties of friendship formation and similarity relating to risk behaviors. Furthermore, the results of the model show that the model has sufficient explanatory power as well as the ability to raise new questions or possible explanations for perceived phenomena in social and developmental psychology, such as: How does friendship dissolve, how does similarity change over time, what are the components of friendship dissolution and similarity decrease? Thus, the model can inspire further empirical research.

In addition to its strong points, our model has a number of weaknesses. To begin with we should mention that the model is an abstraction or mapping of the real world and it works with certain reductions and limitations. For example, an analysis of possible steady states of the model reveals that in the (very) long run the behaviors will tend to become the same among all agents or among different groups of agents. This long-term result of ending up with completely similar behaviors is not realistic. One way to solve this problem is to limit the timeframe of the model, by assuming

[1] This part of the discussion has been written in collaboration with Nils Schuhmacher.

that there is hardly any real process of interaction that lasts long enough for all participants to become similar. A further development of the model is recommended, e.g., by introducing individual capacity limits for the agents' behaviors.

Secondly, the model mostly produces levels of connectedness that are higher than what we intuitively expect when we think about friendships. A particular feature of the model is that in general the results indicate a very high level of connectedness between the different agents. In reality you would expect a lower percentage of cases of very high connectedness. A general problem is that we have only got sparse information about the underlying distribution of liaisons, isolates and group members in real groups. A possible simple solution for reducing the level of connectedness is to add more agents to the model. This solution should be tested in a future version of the model.

Furthermore, certain factors unquestionably influencing risk behaviors were not accounted for in the model. The general focus of the model lies on the social environment and social interaction. However, personality traits like a low self-esteem (Jessor, 1992) and biological factors such as a low level of control of the prefrontal cortex (Bourgeois, Goldman-Rakic, & Rakic, 1994) can also be risk promoting. These additional factors could be included in the future version of model. But of course, we are not completely sure that by introducing these components the model will result in lower connectedness. We should also not forget that adding additional factors could have the (not always recommendable) consequence of making the model more and more complex. Sargent (1998) explained that the computational costs as well as computational time increase exponentially with the attempt to increase a model's confidence. The aim of completeness has to be balanced with the aim of comprehensibility.

Third the model does not take additional aspects of group stability into account. Whether a group stays stable or dissolves depends on additional factors that are not included in the current model. Mechanisms for dissolution (e.g., changing school, introduction of a new kid in the classroom) should also be taken into account in the further development of the model. Additionally, the model does not explicitly account for cultural differences. Peers or peer groups have a different meaning in different cultures in adolescence (Rothbaum, Pott, Azuma, Miyake, & Weisz, 2000). Although the model has been applied to empirical results mostly found in western culture, we nevertheless assume that the underlying processes are similar across cultures, but it is likely that the parameters will differ for different cultures.

Lastly, the model is about the possible development within a school year. Further development is not described.

Although these limitations should be solved in the next version of the model, we can conclude that this is probably one of the first dynamic systems models of friendship formation, based on principles from the theoretical and empirical literature that can simulate the formation of friendship groups, with a good resemblance with the real formation of groups.

3. The empirical results

Chapter 5 presented the results of our empirical work. Since our primary aim was to understand how similarity changes over time, our empirical study included four measurement points in a year. We collected our data by means of a questionnaire. To improve the ecological validity of our study, we did not limit the study to network data in the respondents' classrooms but also allowed students to nominate individuals of other classrooms as friends. Our empirical study also included a transition phase, namely the transition from a lower to a higher school level, between the first and second measurement. The transition phase served to disentangle selection from influence, since we were able to collect data before the friendships of adolescents was formed (end of the second year of high school) and after the friendship was formed (third year of high school).

The first part of the empirical study sought to answer the following questions: *Are friends more similar than non-friends? How does similarity change during the course of one year?* Our results indicated that on average similarity is higher among friendship couples than in non-friendship couples and that similarity first increases and then decreases during the course of time. Taken all together these results confirmed the similarity hypothesis (Bauman & Ennett, 1996; Cohen, 1977; Ennett & Bauman, 1994; Kandel, 1978; Kindermann, 2003) and interestingly also indicated that similarity is not a static concept that remains stable over the course of the time. On the contrary, similarity showed a reversed U-shape by increasing in the middle of the school year and decreasing at the end, stabilizing at a higher level than the original position. This finding is in agreement with Bot, Engels, Knibbe and Meeus (2005) who argued that in established and reciprocal friends the similarity is no longer subject to variation, since stable friends have already the same level of similar behaviors. This finding is also consistent with general dynamic growth principles (van Geert, 1994; 1996). We can conclude that increasing similarity in behaviors is a feature that characterizes mostly the first phase of friendships. As friends meet for the first time and start a relationship, the level of knowledge about each other is still relatively low. Therefore, it is more probable that at first they base their relationship on superficial characteristics (e.g., behavioral similarity). After time, the knowledge about each other increases, the time spent together "doing things" may become less significant and other criteria may become more relevant, such as communication clarity, information exchange, the establishment of a common-ground activity, the exploration of similarity and differences, the resolution of conflict, and self-disclosure (Gottman, 1983). To engage in these processes, children and adolescents must have the required cognitive and emotional skills as well as the experience of being liked and positively validated (Aboud & Mendelson, 1996).

The second part of the empirical study wished to answer the following question: *Do friends have similar behaviors before their friendship is formed?*

Among our participants, we found a sub-sample of students who were not friends at t1 but became friends at t2. The results showed that on average they already shared the same types of risk behaviors at t1 (when they were not yet friends) and at t2 (when they had become friends). We also found one couple of future friends that did not present pre-existing similarity, and therefore we claimed that this couple is an example of what we call the "influence process". Similar findings have also been found in the model simulation.

Both the empirical study and the model confirmed that only considering influence mechanisms is no longer sufficient for explaining the dynamics of peer group situation. Adolescents can no longer only be seen as victims of their friends' pressure. They are not forced to start behaviors they do not like or to start friendships with people they do not like or respect. On the contrary, they actively choose their friends on the basis of a personal choice. Of course, this study does not imply that adolescents should choose risky friends and it does not want to imply that choosing, even freely, a risky friend is a good decision. However, this study wishes to suggest that both friendship interactions and peer influences are complex phenomena that involve many properties that evolve over time to eventually form new stable properties, and therefore must be investigated by using appropriate process-based methods. Another consideration we wish to make is that we should not forget that risk behaviors are also encouraged and promoted by adults (for example, on TV or in other mass media). Therefore, only considering friends as the primary factors of influence amounts to a convenient but undesirable strategy to justify adult responsibilities and commercial interests.

4. The strengths of the thesis

One of the main innovative aspects, and in our view also the main strength of our work, is the empirical and theoretical use of the dynamic systems approach in understanding adolescents' development, and in particular peer influence. We see our main contribution to the literature on this topic in the fact that we have disentangled the main properties of influence and selection mechanisms and have translated these in dynamical forms. The dynamic systems approach helped us firstly in reformulating classical hypotheses in a dynamical way and secondly in incorporating dynamical relationships among a variety of properties and components. In turn, our main goal was to generate an overarching theory of how the properties of influence and selection mechanisms change over time and form stable patterns of relationships and behaviors. In short, the dynamic systems approach forced us to go back to the roots of the developmental studies by focusing on the short-term and long-term interactions of properties of psychological phenomena and on how these change over time. The set-up of the mathematical model helped us to give a concrete example of how the dynamic systems concepts can be translated into an empirical and mathematical model. The model has the advantage that it is not static, such as a classic variable-oriented database. On the contrary, the model results can be changed by manipulating its dynamic parameters (which are fixed at the start of each processing run) or by adding new components (e.g., a new behavior) or new rules (e.g., rule of friendship dissolution). The use of mathematical process models to test theoretical assumptions is still relatively rare in developmental research and can be considered not only a strength but also as our main contribution to the field.

We believe that our empirical design represents another major strength of our work. We measured the behaviors of our sample four times in a year. Although our study cannot be considered an intensive study, it has the advantage of having enough measurement points to make it possible to capture relatively short-term changes of the behaviors and the interactions among the adolescents. This is still relatively rare in developmental researches, which still mostly use longitudinal designs with one year time intervals. Furthermore, the year under study in this work included a transition phase, namely the transition from a lower to a higher school level. By using this transition we were able to assess the similarity of behaviors among friends previous to their friendship formation (i.e., pre-existing similarity). Designs that capture pre-existing similarity are essential for disentangling influence from selection. We hope that our strategy can be further used in studies with larger samples.

Lastly, we believe that another important strength of this thesis is the simultaneous application of different methods (i.e., theoretical, mathematical and empirical) to deepen a well-studied topic such as the development of risk behaviors during adolescence. By using this approach we shed some new lights into the topic.

On a theoretical level (chapters 2 and 3), our contributions are as follows:

- we set up a dynamical theory of risk behaviors and friendships interactions during adolescence
- we emphasized the role of evaluation as a motor of behavioral changes
- we disentangled the properties of influence and selection mechanisms and translated these into dynamical forms

On a mathematical level (chapters 3 and 4), we made:

- a mathematical distinction between reinforcement and influence
- a clear distinction between short-term and long-term interactions
- a clear distinction between properties and rules of influence and selection mechanisms
- a contribution to showing the longitudinal changes of the properties of the model over time

Finally, on an empirical level (chapter 5), we:

- tested how similarity of behavior changes over time
- tested and confirmed the pre-existing-similarity hypothesis
- qualitatively validated the model results with the empirical data

5. The limitations of the thesis

An important limitation of the study is related to the size of our empirical sample. We started the research with a relatively good sample size (n = 74) but through the four measurements we lost

18 students. The drop-out was mostly due to practical issues, e.g., not being present in the further measurements due to sickness or due to change of the classroom group. The sample that we used foresting the pre-existing similarity hypothesis was even smaller (n = 13). Of course, we are aware that this small sample size has negative consequences for the generalizability of our findings. However, we believe that our results still have a high exploratory value and may offer a dawn of new ideas for further researchers.

Another limitation of our empirical study is the fact that we did not consider the influence of the friends who were not part of the school settings. Although we did not limit the friendships nominations to the school class, we did not check the influence of the outside friends. We believe that adolescents have also friends outside the school (as e.g., neighborhood friends, siblings 'friends, previous school friends) who may still be important sources of influence. We suggested that in the future more studies should try to gain more information about the influence of the outside school friends. For example, it could be interesting to check the change over time of behavioral similarity of non-school friends. In particular, it could be interesting to understand what brings the non-school friends together, what makes them breaking up their relationship and whether the same types of properties and dynamical laws of change of school friends can be applied to non-school friends.

In addition to the limitations of our empirical study, we should also mention the limitations related to our model. First of all, our model is an isolated world. The 20 agents that compose our model do not have interactions with others outside the model. Furthermore, our agents are characterized by only ten properties. Of course, we are aware that real adolescents are much more complex and multifaceted and live in a richer environment than our agents. However, dynamic systems modeling does not aim to perfectly reproduce reality. On the contrary, it aims to reduce phenomena to a minimum number of meaningful properties and see whether this minimum number is enough to reach at a nontrivial understanding of how these phenomena work. However, we should never forget that reality is richer and more complex. Therefore, what we achieved with our model is just a simple but hopefully also important grasp of a larger phenomenon.

Secondly, the model has been developed in Excel and is implemented in the form of a Visual basic (VB) for Applications model. Although Excel and VB are available in all computers, for developmental psychologists it is not yet common to use these devices to compute statistical calculations or develop a simulation model. Of course, this limitation could be overcome by collaborating with experts in the field of computer science or mathematics (like it was in our case) or by teaching more modeling and programming skills to the new generations of psychology students. The last is actually a recommendation that we hope can be soon implemented. We believe that a better knowledge of computer programming or more familiarity with the use of dedicated modeling software which becomes increasingly available will help the diffusion of the dynamic systems approach and the use of modeling in psychological researches.

Lastly, our model has been only qualitatively validated. Our validation was based on a general comparison of the model results with the empirical data results. This comparison did not include empirical quantitative techniques such as fitting averages or fitting distribution (see for example, Steenbeek & van Geert, 2008). Nevertheless, we believe that the general qualitative validation of a broad range of important phenomena is a crucial first step in dynamic theory building, and also that our validation has given us an effective indication of how good the model is in predicting friendship and homogeneity. Furthermore, the qualitative validation shows that the model is able to reproduce major properties and processes of reality.

6. Practical implications

We believe that the model that we have presented here and comparable models are not just abstract technological devices that can be used only by technically advanced researchers. On the contrary we believe that these types of models can be constructively used by professionals in different fields to improve everyday problems. For example, these types of models could be useful in professional training settings (e.g., for counselors and clinical youth psychologists) and could even be useful in educational settings such as primary school or high school. These models could teach teachers and professionals where risk behaviors come from and how they develop in the course of time in real settings such as their school classroom. In short, these models can be used as educational tools to give professionals and students a feeling of the dynamic and complex nature of developmental processes, and provide a good way to counter simplistic views on where phenomena such as risk behaviors come from. On the other hand, they also provide a good way to counter the fatalist view that these phenomena are too complicated to be caught in the form of a scientific and explanatory model.

On a more general level, the findings of our model also make interesting applied suggestions. First of all, the findings of our model indicate that it is recommended to organize social introductions among new classmates that focus on positive behaviors, such that adolescents have an opportunity to discover similarities that are primarily based on positive behaviors and personal characteristics. In fact, when educational institutions are organizing introductory camps or meetings for freshmen, they are creating situations that greatly increase the expression of primarily positive and constructive personal properties and behaviors of the participants.

Another suggestion is to try to manipulate evaluations of adolescent behaviors. For instance, teachers could explicitly positively evaluate certain pro-social or academic behaviors in their adolescent students or try to influence the popular adolescents in a group towards more pro-social and pro-academic evaluations. Given the crucial importance of evaluations for the dynamics of engaging in risk as well as in prosocial behavior, it is important that teachers and major social agents act as role models of positive behaviors.

REFERENCES

Aboud, F., & Mendelson, M. J. (1996). Determinants of friendship selection and quality: Developmental perspective. In W.M. Bukowsky, A.F. Newcomb, & W.W. Hartup (Eds.), *The company they keep: Friendship during childhood and adolescence* (pp. 87-112). New York: Cambridge University Press.

Akers, R.L., Krohn M.D., Lanza-Kaduce L., & Radosevich M. J. (1979). Social learning and theory. *American Sociological Review, 44*, 635-55.

Alexander, C. S., Allen, P., Crawford, M. A., & McCormick, L. K. (1999). Taking a first puff: Cigarette smoking experiences among ethnically diverse adolescents. *Ethnicity and Health, 4* (4), 245-257.

Allen, Porter, McFarland, Marsh, & McElhaney (2005). The two faces of adolescents' success with peers: Adolescent popularity, social adaptation, and deviant behavior. *Child Development, 76* (3), 757-760.

Aloise-Young, P.A., Graham, J.W., & Hansen, W.B. (1994). Peer influence on smoking initiation during early adolescence: A comparison of group members and group outsiders. *Journal of Applied Psychology, 79* (2), 281-287.

Arnett, J.J. (1992). Reckless behavior in adolescence: A developmental perspective. *Developmental Review, 12* (4), 339-373.

Arnett, J.J. (1999). Adolescent storm and stress, Reconsidered. *American Psychologist, 54*, 371-386.

Arnett, J.J. (2007). The Myth of peer influence in adolescent smoking initiation. *Health Education & Behavior, 34* (4), 594-607.

Aronson, E., & Worchel, P. (1966). Similarity versus liking as determinants of interpersonal attractiveness. *Psychonomic Science, 5*, 157-158.

Balci, O. (1995). Principles and techniques of simulation validation, verification and testing. *Proceedings of the 1995 Winter Simulation Conference*, 147-154, Arlington,VA,

Ball, Ph. (2004). *Critical mass: How one thing leads to another*. New York: Farrar, Straus and Giroux.

Bandura, A. (1977). *Social Learning Theory*. New York: General Learning Press.

Bauman, K. E., & Ennett, S. T. (1996). On the importance of peer influence for adolescent drug use: Commonly neglected considerations. *Addiction, 91* (2), 185-198.

Baumeister, R. F., & Leary, M.R. (1995). The need to belong: Desire for interpersonal attachments as a fundamental human motivation. *Psychological Bulletin, 117* (3), 497-529.

Berndt, T.J (1979). Developmental changes in conformity to peers and parents. *Developmental Psychology, 15* (6), 608-616.

Berndt, T.J., & Keefe, K. (1995). Friends' influence on adolescents' adjustment to school. *Child Development, 66*, 1312-1329.

Borgatti, S. P. (2002). *NetDraw: Graph visualization software* [computer software]. Harvard, MA: Analytic Technologies.

Bosma, H. A., & Jackson, S. (1990).(Eds.). *Coping and Self in Adolescence*. Berlin: Springer.

Bosma, H.A., & Kunnen, E.S. (2001). Determinants and mechanisms in ego identity development: A review and synthesis. *Developmental Review, 21*, 39-66.

Bot, S.M., Engels, R.C.M.E., Knibbe, R.A., & Meeus, W. (2005). Friend's drinking and adolescent' alcohol consumption: The moderating role of friendship characteristics. *Addictive Behaviors, 30*, 929-947.

Bourgeois, J.P., Goldman-Rakic, P.S., & Rakic P. (1994) Synaptogenesis in the prefrontal cortex of rhesus monkeys. *Cereb Cortex, 4* (1), 78–96.

Boxer, P., Guerra, N. G., Huesmann, L. R., & Morales, J. (2005). Proximal peer level effects of a small group selected prevention on aggression in elementary school children: An investigation of the peer contagion hypothesis. *Journal of Abnormal Child Psychology, 33* (3), 325-338.

Boyer, T.W. (2006). The development of risk-taking: A multi-perspective review. *Developmental Review, 26*, 291-345.

Brown, B.B., Clasen, D.R., & Eicher, S.A. (1986). Perception of peer pressure, peer conformity dispositions, and self-reported behavior among adolescents. *Developmental Psychology, 22* (4), 521-530

Brown, B. B, & Klute, C. (2003). Friendships, Cliques, and Crowds. In G. R. Adams & M. D. Berzonsky (Eds.), Blackwell *Handbook of adolescence* (pp. 330-348). New York: Blackwell.

Brown, B.B., & Theobald, W.E. (1999). How peers matter: *A research synthesis on peer influences on adolescent pregnancy*. Washington, DC: National Campaign to Prevent Teen pregnancy.

Bukowski W.M., Newcomb, A.F., & Hartup W.W. (Eds.). (1996). *The company they keep: Friendship during childhood and adolescence*. New York: Cambridge University Press.

Bukowski, W. M., Sippola, L. K., & Newcomb, A. F. (2000). Variations in patterns of attraction to same- and other-sex peers during early adolescence. *Developmental Psychology, 36* (2), 147-154.

Burk, W.J., Steglich, C.E.G., & Snijders, T.A.B. (2007). Beyond dyadic interdependence: Actor-oriented models for co-evolving social networks and individual behaviors. *International Journal of Behavioral Development, 31*, 397-404.

Byrne, D. (1971). *The Attraction Paradigm*. New York: Academic Press.

Cairns, R.B, & Cairns, B.D. (1994). *Lifelines and risks: Pathways of youth in our time*. New York, NY: Cambridge University Press.

Casey B.J., Getz S., & Galvan, A.(2008). The adolescent brain. *Developmental Review, 28* (1), 62–77.

Cillessen, A.H.N., & Mayeux, L. (2004). From censure to reinforcement: Developmental changes in the association between aggression and social status. *Child Development, 75*, 147–163.

Cohen, J.M. (1977). Sources of peer group homogeneity. *Sociology of Education, 50*, 227-24.

Coie, J.D., Dodge, K.A., & Coppotelli, H. (1982). Dimensions and types of social status: A cross-age perspective. *Developmental Psychology, 18*, 557–570.

Coleman, J. S. (1961). *The adolescent society*. Oxford England: Free Press of Glencoe.

Conrad, K.M., Flay, B.R., & Hill, D. (1992). Why children start smoking cigarettes: Predictors of onset. *British Journal of Addiction, 87* (12), 1711-1724.

Crone, E. A. (2008). *Het puberende brein: Over de ontwikkeling van de hersenen in de unieke periode van de adolescentie*. Uitgeverij Bert Bakker/ Prometheus.

Cunningham, W. A., Zelazo, P. D., Packer, D. J., & Van Bavel, J. J. (2007). The Iterative reprocessing model: A multilevel framework for attitudes and evaluation. *Social Cognition, 25* (5), 736-760.

Deković, M. (1999). Risk and protective factors in the development of problem behavior during adolescence. *Journal of Youth and Adolescence, 28* (6), 667–685.

Denscombe, M. (2001). Smoking cessation among young people: The need for qualitative research on young people's experiences of giving up tobacco smoking. *Health Education Journal, 60* (3), 221-31.

Dijkstra, J.K., Lindenberg, S., Verhulst, F.C., Ormel, J., & Veenstra, R. (2009). The relation between popularity and aggressive, destructive, and norm-breaking behaviors: Moderating effects of athletic abilities, physical attractiveness, and prosociality. *Journal of Research on Adolescence, 19* (3), 401-413.

Dishion, T.J., Bullock, B.M. & Granic, I. (2002). Pragmatism in modeling peer influence: Dynamics, outcomes, and change processes. How prevention intervention studies in the field of developmental psychopathology can inform developmental theories and models. *Development and Psychopathology, 14* (4), 969-981.

Dishion, T. J., & Loeber, R. (1985). Adolescent marijuana and alcohol use: The role of parents and peers revisited. *American Journal of Drug and Alcohol Abuse, 11*, 11-25.

Dishion, T.J., Nelson, S.E., Winter, C.E., & Bullock, B.M. (2004). Adolescent friendship as a dynamic system: Entropy and deviance in the etiology and course of male antisocial behavior. *Journal of Abnormal Child Psychology, 32* (6), 651–663.

Dishion T.J., Spracklen, K.M., Andrews, D.W., & Patterson, G. (1996). Deviancy training in male adolescent friendships. *Behavior Therapy, 27*, 373-390.

Dunphy, D. (1963). The social structure of urban adolescent peer groups. *Sociometry, 26*, 230-246.

Elliott, D. S., Huizinga, D., & Ageton, S. S. (1985). *Explaining Delinquency and Drug Use*. Beverly Hills, CA: Sage.

Engels, R.C.M.E (1998). Forbidden Fruits. *Social dynamics in Smoking and Drinking Behavior of Adolescents*. Maastricht: Universitaire Pers, Maastricht.

Engels, R.C.M.E., & Bogt, T. ter (2001). Influences of risk behaviors on the quality of peer relations in adolescence. *Journal of Youth and Adolescence, 30* (6), 675-696.

Engels, R.C.M.E., Knibbe, R.A., Drop, M.J. & De Haan, Y.T. (1997). Homogeneity of cigarettes smoking within peer groups: Influence or selection? *Health Education & Behavior, 24*, 801-811.

Ennett S.T., &. Bauman, K.E. (1994). The contribution of influence and selection to adolescent peer group homogeneity: The case of adolescent cigarette smoking. *Journal of Personality and Social Psychology, 67*, 653-663.

Ennett, S. T., & Bauman, K. E. (1996). Adolescent social networks: School, demographic, and longitudinal considerations. *Journal of Adolescent Research, 11*(2), 194-215.

Ennett, S. T., Bauman, K. E., & Koch, G. G. (1994). Variability in cigarette smoking within and between adolescent friendship cliques. *Addictive Behaviors, 19* (4), 295-305.

Epstein, J. M., & Axtell, R. (1996). *2050 project. Growing artificial societies: social sciences from the bottom up*. Washington, DC: Brookings Inst. Press.

Erikson, E. H. (1968). *Identity: Youth and Crisis*. New York: Norton.

Espelage, D. L., Holt, M. K., & Henkel, R. R. (2003). Examination of Peer–Group contextual effects on aggression during early adolescence. *Child Development, 74*, 205-220.

Fagiolo, G., Birchenhall, C., & Windrum, P. (2007). Empirical validation in agent-based models: Introduction to the special issue. *Computational Economics, 30* (3), 189-194.

Fogel, A. (1993). *Developing through relationship: Origins of communication, self, and culture*. London: Harvester-Wheatsheaf.

Frijda, N. H. (1986). *The emotions: studies in emotion and social interaction*. London: Cambridge University Press.

Gardner, M., & Steinberg, L., 2005. Peer influence on risk taking, risk preference, and risky decision making in adolescence and adulthood: an experimental study. *Developmental Psychology 41* (4), 625–635.

Gaughan, M. (1999). *Predisposition and Pressure. Getting Drunk in Adolescent Friendships*. UMIPROQuest Digital Dissertations

Gilbert, N., & Troitzsch, K.G. (1999). *Simulation for the Social Scientist*. Milton Keynes: Open University Press.

Good, P.I. (1999). *Resampling methods: a practical guide to data analysis*. Boston: Birkhäuser.

Gottman, J. (1983). How children become friends. *Monographs of the Society for Research in Child Development, 48* (3), 1-86.

Graham, J. W., Marks, G., & Hansen, W. B. (1991). Social influence processes affecting adolescent substance use. *Journal of Applied Psychology, 76* (2), 291-298.

Granic, I. (2000). The self-organization of parent-child relations. Beyond bidirectional models. In M. D. Lewis & I. Granic, (Eds.), *Emotion, development and self-organization. Dynamic systems approaches to emotional development* (pp. 267-298). New York Cambridge: University Press

Granic I., & Dishion T. J., (2003). Deviant talk in adolescent friendships: A step toward measuring a pathogenetic attractor process. *Social Development, 12*, 314-334.

Granic, I., Dishion, T. J., & Hollenstein, T. (2003). The family ecology of adolescence: A dynamic systems perspective on normative development. In G. R. Adams & M. Berzonsky (Eds.), Blackwell *Handbook of Adolescence* (pp. 60-91). New York: Blackwell.

Granic, I., & Hollenstein, T. (2003). Dynamic systems methods for models of developmental psychopathology. *Development and Psychopathology, 15*, 641-669.

Granic I., & Patterson, G.R. (2006). Towards a comprehensive model of antisocial development: A dynamic systems approach. *Psychological Review, 113* (1), 101-131.

GüroĐlu, B., Van Lieshout, C. F. M., Haselager, G. J. T., & Scholte, R. H. J. (2007). Similarity and Complementarity of Behavioral Profiles of Friendship Types and Types of Friends: Friendships and Psychosocial Adjustment. *Journal of Research on Adolescence, 17* (2), 357–386.

Hales, D., Rouchier, J., & Edmonds, B. (2003). Model-to-model analysis. *Journal of Artificial Societies and Social Simulation, 6* (4), 5.

Hallinan, M.T. (1979). Structural effects on children's friendships and cliques. *Social Psychology Quarterly, 42* (1), 43-54.

Hallinan, M.T., & Smith, S. (1989). Classroom characteristics and student friendship cliques. *Social Forces, 67*, 898-919.

Hanneman, R. A., & Riddle, M. (2005). *Introduction to social network methods*. Retrieved from http://faculty.ucr.edu/~hanneman/

Harris, J. (1998). *The nurture Assumption: Why Children turn out the way they do*. New York: Free Press.

Hartup, W.W. (1983). Peer Relations. In P.H. Mussen (Serie Ed.) and E.M. Hetherington (Vol. Ed.) Handbook of Child Psychology. Vol. 4. Socialization, Personality and Social Development (pp.103 – 196). New York: Wiley & Sons.

Hartup, W.W. (1993). Adolescents and their friends. In B. Lauresen (Ed.). *New directions for child development: close Friendship in adolescence* (pp. 3-22). San Francisco: Jossey-Bass

Hartup, W.W., & Stevens, N. (1997). Friendship and adaptation in the life course. *Psychological Bulletin, 121*, 335-370.

Hawkins, J.D., Catalano, R.F., & Miller, J.Y. (1992). Risk and protective factors for alcohol and other drug problems in adolescence and early childhood: Implications for substance abuse prevention program. *Psychological Bulletin, 112* (1), 64-105.

Henrich, C. C., Kuperminc, G. P., Sack, A., Blatt, S. J., & Leadbeater, B. J. (2000). Characteristics and homogeneity of early adolescent friendship groups: A comparison of male and female clique and nonclique members. *Applied Developmental Science, 4* (1), 15-26.

Hoffman, B.R., Monge, P.R., Chou, C.P., & Valente, TW. (2007). Perceived peer influence and peer selection on adolescent smoking. *Addictive Behaviors, 32*, 1546-1554.

Hood, G. M. (2010). *PopTools version 3.2.5.* Available on the internet. URL http://www.poptools.org

Houtzager, B. & Baerveldt, C. (1999). Just like normal. A social network study of the relation between petty crime and the intimacy of adolescent friendships. *Social Behavior and Personality, 27* (2), 177-192.

Howe, M.L., & Lewis, M.D. (2005). The importance of dynamic systems approaches for understanding development. *Developmental Review, 25*, 247-251.

Inhelder, B., & Piaget, J. (1958). *The Growth of Logical Thinking from Childhood to Adolescence*. Basic Books, New York, NY.

Irwin, C.E. Jr. (1993). Adolescent and risk taking: How are they related? In N.J. Bell & R.W. Bell (Eds.), *Adolescent risk taking*. Newbury Park, CA, US: Sage Publications.

Izard, C. (1977). Human Emotions. Plenum Press, New York.

Jackson, A.E. (1987). *Perceptions of a new acquaintance in adolescence*. University of Groningen: Unpublished doctoral dissertation.

Jackson, A.E. (1993). Social behaviour in adolescence: The analysis of social interaction sequences. In In Jackson, S., & Rodriquez-Tome', H. (Eds.), *Adolescence and Its Social Worlds* (pp.15-45), Hillsdale, NJ: Lawrence Erlbaum.

Jackson, A.E. & Rodriguez-Tomé (Eds.). (1993). *Adolescence and its social worlds*. Hillsdale, NJ: Lawrence Erlbaum.

Jessor, R., (1992). Risk behavior in Adolescence: A Psychosocial Framework for understanding and action. *Developmental Review, 12*, 374-390.

Jessor, R., Donova., J.E. & Costa, F. M. (1992). *Health behavior questionnaire*. Institute of Behavioral Science, University of Colorado, Boulder, U.S.A.

Jessor, R., & Jessor, S. L. (1977). *Problem behavior and psychosocial development: A longitudinal study of youth.* New York: Academic Press.

Jessor, R., Turbin, M. S., & Costa, F. M. (1998). Protective factors in adolescent health behavior. *Journal of Personality and Social Psychology, 75* (3), 788-800.

Jones, M.B., & Offord, D.R. (1989). Reduction of antisocial behavior in poor children by nonschool skill-development. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 30*, 737–750.

Kalick, S. M., & Hamilton, T. E. (1986). The matching hypothesis reexamined. *Journal of Personality and Social Psychology, 51* (4), 673-682.

Kandel, D. (1978). Homophily, selection, and socialization in adolescent friendships. *American Journal of Sociology, 84*, 427-436.

Kandel, D. B., & Davies, M. (1991). Friendship networks, intimacy, and illicit drug use in young adulthood: A comparison of two competing theories. *Criminology, 29* (3), 441-469.

Kaplan, E.H. (1991). Adolescents age fifteen to eighteen: A psychoanalytic developmental review. In S.I. Greenspan & G. H. Pollock (Eds.), *The course of life: Adolescence*, Vol. 4, (pp.201-233). Madison, WI: International Universities Press.

Keefe, K. (1994). Perceptions of normative social pressure and attitudes toward alcohol use: Change during adolescence. *Journal of Studies on Alcohol, 55*, 46-54.

Keller, M. (2004). A Cross-cultural perspective on friendship research. *Newsletter of the International Society for the Study of Behavioral Development Newsletter, 28*, 10-14.

Kindermann, T. A. (2003). Children's relationship and development of person-context relations. In J. Valsiner & K. Connnoly (Eds.), *Handbook of Developmental Psychology* (pp.407-430). London: Sage publications.

Kirke, D.M. (2004). Chain reactions in adolescents' cigarette, alcohol and drug use: Similarity through peer influence or the patterning of ties in peer networks? *Social Networks, 26* (1), 3–28.

Kiuru, N., Burk, W., Laursen, B., Salmela-Aro, K., & Nurmi, J.-E. (2010). Pressure to drink but not to smoke: Disentangling selection and socialization in adolescent peer networks and peer groups. *Journal of Adolescence, 33* (6), 801−812.

Knecht, A., (2008). *Friendship Selection and Friends' Influence. Dynamics of Networks and Actor Attributes in Early Adolescence*. PhD dissertation, University of Utrecht.

Krengel, U. (2005). *Einführung in die Wahrscheinlichkeitstheorie und Statistik: [für Studium,Berufspraxis und Lehramt]* Vieweg.

Kung, E.M., & Farrell, A.D. (2000). The role of parents in early adolescent substance abuse: An examination of mediating and moderating effects. *Journal of Child and Family studies, 9*, 509-528.

Kunnen, E.S., & Bosma, H.A. (2000). Development of meaning making: A dynamic systems approach. *New Ideas in Psychology, 18*, 57-82.

LaFontana, K. M., & Cillessen, A. H. N. (1998). The nature of children's stereotypes of popularity. *Social Development, 7*, 301-320.

LaFontana, K.M., & Cillessen, A.H.N. (2002). Children's stereotypes of popular and unpopular peers: A multimethod assessment. *Developmental Psychology, 38*, 635–647.

Larson, R., & Richards, M. H. (1991). Daily companionship in late childhood and early adolescence: Changing developmental contexts. *Child Development, 62*, 284–300.

Latané, B. (1981). The psychology of social impact. *American Psychologist, 36*, 343–356.

Lazarus, R.S. (1982). Thoughts on the relations between emotion and cognition. *American Psychologist, 37*, 1010-1019.

Lewis, M. D. (1995). Cognition-emotion feedback and the self-organization of developmental paths. *Human Development, 38*, 71-102.

Lewis, M. D. (1999). A dynamic systems approach to measuring behavioural flexibility in early personality development. In M. Fingerle & A. Freytag (Eds.), *The strengths of children: Education between risk and resilience* (pp. 328-342). Berlin: Ernst-Reinhardt-Verlag.

Lewis, M.D. (2000). The promise of dynamic systems approaches for an integrated account of human development. *Child Development, 71*, 36-43.

Lewis, M.D. (2005). Bridging emotion theory and neurobiology through dynamic systems modeling. *Behavioral and Brain Sciences, 28*, 169-194.

Lewis, M.D. & Granic, I. (Eds.). (2000). E*motion, development, and self-organization: Dynamic Systems Approaches to Emotional Development*. New York: Cambridge University Press

Lichtwarck-Aschoff, A., van Geert, P. , Bosma, H.A., & Kunnen, S.(2008). Time and Identity: A framework for research and theory formation. *Developmental Review, 28*, 370-400.

Maggs, J.L., Almeida, D.M., & Galambos, N.L. (1995). Risky business: The paradoxical meaning of problem behavior for young adolescents. *Journal of Early Adolescence, 15*, 344-362.

Mahoney, J.L. & Stattin, H. (2000). Leisure time activities and adolescent antisocial behavior: The role of structure and social context. *Journal of Adolescence, 23*, 113–127.

Mahoney, J.L. (2000). Participation in school extracurricular activities as a moderator in the development of antisocial patterns. *Child Development, 71*, 502–516.

Manly, B.F. (1997). *Randomization, bootstrap and Monte Carlo methods in biology* (2nd ed.). London: Chapman and Hall.

Marcia, J.E. (1966). Development and validation of ego-identity status. J*ournal of Personality and Social Psychology, 3* (5), 551-558.

Mayeux, L., & Cillessen, A.H.N. (2007). Peer influence and the development of antisocial behavior. In R.C.M.E. Engels, M. Kerr & H. Stattin (Eds.). *Friends, lovers and Groups. Key relationship in adolescence*. West Sussex, England: John Wiley & Sons.

Moffitt, T. E. (1993). Life-course-persistent and Adolescence-limited Antisocial Behavior: A developmental taxonomy. *Psychological Review, 100*, 674-701.

Moore, D. S., & McCabe, G. P. (2006). *Introduction to the practice of statistics* (5th ed.).New York: Freeman and Company.

Newcomb, A. F., Bukowski, W. M., & Pattee, L. (1993). Children's peer relations: A meta-analytic review of popular, rejected, neglected, controversial, and average sociometric status. *Psychological Bulletin, 113* (1), 99-128.

Noom, M.J., Dekovic, M. & Meeus, W.H.J. (1996). Opvoeding en ontwikkeling in de adolescentie [Child-rearing and development during adolescence]. In Rispens, J., Hermanns, J.M.A., and Meuus, W.H.J. (Red.), *Opvoeden in Nederlad*. Van Gorcum, Assen, pp.207-226

Norton, A. (1995). Dynamics: An introduction. In T. van Gelder & R.F. Port (Eds.), Mind as motion. *Explorations in the Dynamics of Cognition*. Cambridge, Massachusetts: the MIT Press.

Olthof, T., Kunnen, E. S., & Boom, J. (2000). Simulating mother-child interaction: Exploring two varieties of a non-linear dynamic systems approach. *Infant and Child Development, 9*, 33-60.

Patterson, G. R., & Dishion, T. J. (1985). Contributions of families and peers to delinquency. *Criminology, 23* (1), 63-79.

Piaget, J. & Inhelder, B. (1969). *The Psychology of the Child*. New York: Basic Books.

Popp, D., Laursen, B., Kerr, M., Stattin, H. & Burk, W.J. (2008). Modeling homophily over time with an Actor-Partner Interdependence Model. *Developmental Psychology, 44*, 1028 – 1039.

Rosenblum, G.D., & Lewis M. D. (2003). Emotional development in Adolescence. In G. R. Adams & M. Berzonsky (Eds.), Blackwell *Handbook of adolescence* (pp. 269-289). New York: Blackwell.

Rothbaum, F., Pott, M., Azuma, H., Miyake, K., & Weisz, J. (2000). The development of close relationships in Japan and the United States: Paths of symbiotic harmony and generative tension. *Child Development, 71* (5), 1121-1142.

Sargent, R. G. (1998). Verification and validation of simulation models. In *Proceedings of Winter Simulation Conference*, pp.121-130.

Schuhmacher, N. (2009). *Group Formation in Class and Peer Influences towards Risk Behaviour – A Dynamic Systems Approach*. (Unpublished master thesis). University of Osnabrück: Osnabrück.

Schulenberg, J., Maggs, J. L., Dielman, T. E., Leech, S. L., Kloska, D. D., Shope, J. T., & Laetz, V. B. (1999). On peer influences to get drunk: A panel study of young adolescents. *Merrill- Palmer Quarterly, 45*(1), 108-141.

Shedler, J., & Block, J. (1990). Adolescent drug use and psychological health: *A longitudinal inquiry. American Psychologist, 45*, 612-30.

Simon, J. L. (1997). The Procedures of Monte Carlo Simulation (and Resampling). In: *Resampling: The New Statistics* (pp. 154-158). Retrieved from http://www.resample.com/content/text/index.shtml

Smith, E. R., & Conrey, F. R., (2007) Agent-Based Modeling: A New Approach for Theory Building in Social Psychology, *Personality and Social Psychology Review, 11*, 87-104.

Snijders, T.A.B., van de Bunt, G.G., & Steglich, C.E.G. (2010). Introduction to actor-based models for network dynamics. *Social Networks, 32*, 44-60.

Spear, L.P. (2000). The adolescent brain and the age-related behavioural manifestation. *Neuroscience and Biobehavioural Reviews, 24*, 417-463.

Steenbeek, H., & van Geert, P.L.C. (2005). A dynamic systems model of dyadic play interaction in children. *European Journal of Developmental Psychology, 2* (2), 105-145.

Steenbeek, H., & Van Geert, P.L.C. (2007). A theory and dynamic model of dyadic interaction: Concerns, appraisals and contagiousness in a developmental context. *Developmental Review, 27*, 1-40.

Steenbeek. H., & Van Geert, P.L.C. (2008). An empirical validation of a dynamic systems model of interaction: Do children of different sociometric statuses differ in their dyadic play interactions? *Developmental Science, 11*, 253-281.

Steglich, C, Snijders, T.A.B, & Pearson, M. (2010). Dynamic networks and behavior: Separating selection from influence. *Sociological Methodology, 40*, 329–393.

Steinberg, L. (2004). Risk-taking in adolescence: What changes, and why? *Annals of the New York Academy of Sciences, 1021*, 51–58.

Sullivan, H.S. (1953). *The interpersonal theory of psychiatry*. New York: Norton

Thelen, E., & Smith, L. (1994). *A dynamic system approach to the development of cognition and action*. Cambridge, MA: MIT Press.

Troitzsch, K. G. (2004). Validating simulation models. In *Proceedings 18th European Simulation Multiconference*, 265-270.

Urberg, K. A., DeĐirmencioglu, S. M., & Tolson, J. M. (1998). Adolescent friendship selection and termination: The role of similarity. *Journal of Social and Personal Relationships, 15* (5), 703–710.

Urberg, K.A., DeĐirmencioĐlu, S.M., & Pilgrim, C. (1997). Close friends and group influence on adolescent cigarette smoking and alcohol use. *Developmental psychology, 33* (5), 834-844.

Urberg, K. A., Luo, Q., Pilgrim, C., & Degirmencioglu, S. M. (2003). A two-stage model of peer influence in adolescent substance use: Individual and relationship-specific differences in susceptibility to influence. *Addictive Behaviors, 28*, 1243-1256.

Urberg, K.A., Shyu, S.J., & Liang, J. (1990). Peer influence in adolescent cigarette smoking. *Addictive Behaviors, 115*, 247-255.

van der Maas, H.L.J., & Molenaar, P.C.M. (1992). Stagewise cognitive development: An application of catastrophe theory. *Psychological Review, 99*, 395-417.

van Eerde (2005). *Risico gedrag tijdens adolescentie: Een kwalitatief onderzoek naar percepties van docenten en leerlingen omtrent verschillende aspecten van risicogedrag*. (Unpublished bachelor thesis). Rijksuniversiteit Groningen, Groningen.

van Geert, P. (1994). Dynamic systems of development. Change between complexity and chaos. New York: Harvester.

van Geert, P.L.C. (1996). A dynamic developmental model of suicide. Commentary. *Human Development, 39* (3), 195-199.

van Geert, P. (2003). Dynamic systems approaches and modeling of developmental processes. In J. Valsiner & K. J. Conolly (Eds.), *Handbook of developmental Psychology* (pp. 640-672). London: Sage publications Ltd.

van Geert, P. (2008). Nonlinear-Complex-Dynamic-Systems in developmental psychology. In Guastello, S., Koopmans, M. and Pincus, D. (Eds.). *Chaos and Complexity: The Theory of Nonlinear Dynamical Systems Psychology* (pp.242-281). Cambridge: Cambridge University Press

van Geert, P., & Steenbeek, H. (2005). Explaining after by before. Basic aspects of a dynamic systems approach to the study of development. *Developmental Review, 25*, 408-442

Waite, M. (2006). *VisualBots VisualProgramming for Agent-Based Simulation (Version1.6)* [computer software]. Available from http://www.visualbots.com/downloads.htm.

Wang, M.Q., Fitzhugh, E.C., Westerfield, R.C., & Eddie, J.M. (1995). Family and peer influences on smoking behavior among American adolescents: An age trend. *Journal of Adolescent Health, 16*, 200-203.

Weisstein, E. W. (1999). *CRC concise encyclopedia of mathematics*. Boca Raton-New York: CRC Press.

Werner, M. J. (1991). *Adolescent substance abuse: Risk factors and prevention strategies*, Maternal and Child Health Technical Information Bulletin. National Center for Education in Maternal and Child Health, Washington D.C.

WHO (2002). *The World Health Report, Reducing Risks, Promoting healthy Life*. Geneva: World Health Organization.

Youniss, J., & Smoller, J. (1985). *Adolescent relations with mothers, fathers and friends*. Chicago: University of Chicago Press.

Zeigler, B. P. (1985). *Theory of modeling and simulation*. Malabar, Fla.: Krieger.

APPENDICES

Appendix A: Choice of Parameter Ranges

A major challenge when developing a model is the question: How to find suitable parameter ranges or settings? The following parameter ranges were defined whether on the basis of theoretical considerations, the modelers experience due to the conducting of multiple test runs, or an the basis of empirical findings.

Change rate

This parameter controls the speed of learning of or adopting to the behavior of the other agents. An import question before we start to find a suitable parameter range for c is: How long do adolescents need to become homogenous? For example: How long does a non-smoker need, who enters a group of smokers, to adapt his or her smoking behavior to the average group behavior? Or how fast does an adolescent change the average marihuana consume during a school year? Usable empirical findings for defining a suitable range for our parameter c were rare. A suitable range has been estimated on the basis of model experience.
The change rate seems to be crucial for the behavioral change. A suitable range is [0.005; 0.0005]. A value bigger than 0.005 leads to a too strong and fast change in behavior. A value smaller than 0.0005 has leads to very small behavioral change.

Effect reduction

The effect reduction has an influence on how fast preferences grow and respectively decrease. Having a high value for effect reduction means that preferences change quite fast, they can increase faster as well as drop faster. To find a suitable parameter value and a range of realistic values, we have to make some theoretical assumptions. In general the process of preference formation is quite fast. Quite fast means within a couple of weeks. To find a lower boundary let us assume that we have got two agents with an initially low preference for each other. But at the same time both agents are quite similar (this is generally possible in the model). In this case the agents should be able to form a friendship within a school year.
There are only few empirical findings about the duration of friendships or non-friendships. For example, Hallinan (1979) described a longitudinal study on friendship formation in 4 classes of 6th graders and 1 class of 4th graders. For the 6th graders the absence of dyads (friendships) lasted from 189 to 400 days.
If we have only got a look at the logistic growth function for the preference and set $S_{t+1}^{ij} - \theta_S$ to a fixed value, we are able to estimate a suitable parameter range for *r*. With *r* set to 0.05, we need 716 simulation steps (or about 72 simulated school days) to reach a preference value of 0.8 with an initial preference value of 0.1 and $S_{t+1}^{ij} - \theta_S = 0{,}1 \; \forall t$. This gives us a lower bound for the for-

mation of a friendship with initially low preference. With *r* set to 0.01 we need 3583 (or about 358 simulated school days) steps to reach a preference value of 0.8 (with same constraints like before). This defines our upper bound for a friendship formation with initially low preferences. Therefore a suitable parameter range for *r* is [0.01; 0.05].

Alpha

Alpha indicates the amount of time that is needed until an agent can perceive the real behavioral profile of another agent. The idea is that at the beginning it is not clearly visible how other agents really behave. The more time the agents spend together the more visible becomes their true behavioral profile. The decrease is exponential, Alpha can range from 0.0001 to 0.000001. With alpha chosen within this range, a reduction of an average initial distortion of 0.4 to nearly 0 approximately needs 300 to 4000 iteration steps.

Theta perceived similarity

Theta perceived similarity is used for calculating the preference. It gives the threshold for an increase or a decrease in preference. Is the perceived similarity above theta perceived similarity we have an increase in preferences else preference drops. In general the similarity should be higher than 0.5 for an increase. This means that an agent still has an average deviation of 0.5 in all behaviors compared with another agent, so he is 50% "different" from the other agent. A suitable range for theta perceived similarity range would be 0.7 to 0.8. In this case, an agent can tolerate an average difference of 20% - 30% percent and is still able then to start liking another agent.

Theta similarity

Theta similarity is used as a threshold to calculate the interaction value. If the true similarity is above this threshold, it is very likely that an agent has a positive interaction with the other agent. If it is below, it is probable to have a negative interaction with the other agent. Again a theta similarity value between 0.7 and 0.8 can be seen as suitable.

Min mutuality, max mutuality

Min mutuality and max mutuality have in influence on the decision if an interaction takes place, or not. If the mutuality value is below min mutuality, it is set to min mutuality. In general this guarantees that an interaction is still possible though there might be a very low mutuality value for two agents. On the other hand, if the mutuality value is above max mutuality, the mutuality value is set to max mutuality. This guarantees that you do not always interact with an agent you like. Suitable value ranges are from 0.0 to 0.2 for min mutuality and 0.8 to 1.0 for max mutuality.

SD interaction value

SD interaction value indicates the standard deviation for sampling the interaction value. The higher this value, the higher the deviation of the interaction value from the average interaction value that is defined on the basis of the normalized similarity. An average deviation of 0.2 is defined as common, a range from 0.0 (nearly no deviation) to 0.4 (which indicates a moderate deviation) is suitable for *SD* interaction value.

SD initial preference (optional), SD initial perceived behavior (optional)

When initialization the model there is given the option to draw the initial preference values as randomly from a normal distribution with the initially perceived similarity set as average and *SD* initial preference as standard deviation. Otherwise all preferences are drawn randomly from the range 0 to 1 with an equally distributed probability. The higher the value of *SD* initial preference, the higher the deviation from the initial perceived similarity. A suitable range for *SD* initial preference is from 0 to 0.4, where 0 actually means that the initial preference values are equal to the initial values of perceived similarity.
SD initial perceived behavior gives the initial distortion for the perception of the true behavior of the other agents. It is optional, too. If it is not defined or set to 0, the initial distortion value is set to 0 and therefore the perceived behavior equals the true behavior in the simulation run. Otherwise the initial values for the perceived behavior are drawn randomly from a normal distribution with the average set to the true initial behavior and *SD* initial perceived behavior as standard deviation. A range from 0.2 to 0.4 is suitable here, too.

Averages for initial populations, SD initial behavior

The initial values for the behavioral profile a randomly drawn from two different normal-distributions. Therefore, we receive two initial agent populations: A risky population and a conventional population (each generally consisting of 10 agents). As mentioned before, empirical findings indicate that there is a modest negative correlation between risk and conventional behavior. Thus, for the risky population the risk behavior for each agent is drawn as a random sample from a normal distribution with mean $\mu_{B1,0} \in [0,6;0,8]$ and the standard deviation $\sigma_{B,0} \in [0,1;0,3]$. Their conventional behavior is drawn from a normal distribution with mean $\mu_{B2,0} \in [0,2;0,4]$ and standard deviation $\sigma_{B,0}$. For the conventional population risk behavior is drawn as a random sample from a normal distribution with mean $\mu_{B2,0}$ and standard deviation $\sigma_{B,0}$, conventional behavior is drawn with $\mu_{B1,0}$ as mean and standard deviation $\sigma_{B,0}$.

Weight factors

The decision for defining a suitable parameter range for the weight factors w_{Pop}, w_V, and w_P have to be made on the basis of the modelers objective. They can be varied to test different assumptions, for example, to compare different scenario, such as a scenario with major impact of popularity on the evaluation with a scenario where evaluation is mainly dependent on the interaction value. As a constraint the sum of all weight factors has to be one ($w_{Pop} + w_P + w_V = 1$). For the parameter setting in the analysis we assumed that in general the interaction value has a stronger impact on the evaluation than the popularity. Nevertheless, the impact of popularity is crucial and therefore should not be chosen too small. The influence of preference was not taken into account.
Therefore $w_{Pop} \in [0,2;0,4]$ and
$w_V \in [0,6;0,8]$ can be chosen as suitable parameter ranges.

Appendix B: Setting for the example in Chapter 4

Parameter	*Value/Range*	*Constraints and Explanations*
General		
Iterations	2000	
Number of agents	20	
Basic		
c	0.002	
r	0.0175	
θ_S	0.75	
$\min_M$	0.2	
$\max_M$	0.8	with $\max_M = 1 - \min_M$
$\min_p$	0.0001	
σ_V	0.1	
ν	2	
Weights		
w_{Pop}	1/3	
w_v	2/3	with $w_v = 1 - w_{Pop}$
Advanced		
α	*n.def.*	Because subjective perception of behavior has been disabled, the distortion value is set to 0 and α can be chosen as an arbitrarily.
θ_S	0.75	with $\theta_S = \theta_S$
θ_P	*n.def.*	Because the value for w_P is set to 0, θ_P can be chosen arbitrarily.
w_P	0	
Initialization		
$\sigma_{P,0}$	*n.def.*	$\sigma_{P,0}$ can be set to an arbitrary number, because the initial preferences are chosen randomly from an equal distribution over 0 to 1.
	0	If we set $\sigma_{B,0}$ to 0, this disables the subjective perception of behavior. So actually all agents perceive the true behavioral profile of al the other agents.
$\sigma_{B,0}$	0.275	
$\mu_{B1,0}$	0.7	
$\mu_{B2,0}$	0.3	with $\mu_{B2,0} = 1 - \mu_{B1,0}$

Appendix C: Parameter setting for the analysis

The parameter values and ranges described below have been used to receive the results of 100 model runs that were the basis for the model analysis.
As a simplification the direct influence of preference on the evaluation has not been taken into account. Therefore the weight factor of preference was set to 0 ($w_P = 0$). Nevertheless there is still the indirect influence of preference on the evaluation via popularity and the interaction (the higher the mutual preference the higher is the general possibility of an interaction and the more an agent is preferred, the higher is his or her popularity).
For each new started simulation run the parameters are randomly drawn from the ranges defined above with an equally distributed probability. Reasons for choosing these specific ranges are given in appendix B. Some parameters are depending on the values of other parameters as described above. E.g. when for a new simulation run minM is drawn as 0.14, maxM is automatically set to 1 - 0.14 = 0.86.
The preference values are initialized as random values drawn from the range [0.1] with an equally distributed possibility. For the initialization of the behavioral profile random values are drawn from two different normally-distributed populations. Correspondingly we receive one initial population of risky agents and one population of conventional agents, though a certain behavioral variation is given due to the choice of $\sigma_{B,0}$ and a lot of mixed behavioral profiles are initially given. Further details for the model initialization are also given in appendix B.

Hints for the notation

n.def.:	not defined
[a;b]:	Interval Notation. A semicolon was used here instead of a comma to avoid confusion with the notation of the decimals.

Parameter	*Value/Range*	*Constraints and Explanations*
General		
Iterations	2000	
Number of agents	20	
Basic		
c	[0.005;0.0005]	
r	[0.01;0.05]	
θ_S	[0.7;0.8]	
$\min_M$	[0.0;0.2]	
$\max_M$	[0.8;1.0]	with $\max_M = 1 - \min_M$
$\min_p$	0.0001	
σ_V	[0.0;0.4]	
ν	2	
Weights		
w_{Pop}	[0.2;0.4]	
w_v	[0.6;0.8]	with $w_v = 1 - w_{Pop}$
Advanced		
α	*n.def.*	Because subjective perception of behavior has been disabled, the distortion value is set to 0 and α can be chosen as an arbitrarily.
θ_S	[0.7;0.8]	with $\theta_S = \theta_S$
θ_P	*n.def.*	Because the value for w_P is set to 0, θ_P can be chosen arbitrarily.
w_P	0	
Initialization		
$\sigma_{P,0}$	*n.def.*	$\sigma_{P,0}$ can be set to an arbitrary number, because the initial preferences are chosen randomly from an equal distribution over 0 to 1.
	0	If we set $\sigma_{B,0}$ to 0, this disables the subjective perception of behavior. So actually all agents perceive the true behavioral profile of al the other agents.
$\sigma_{B,0}$	[0.1;0.3]	
$\mu_{B1,0}$	[0.6;0.8]	
$\mu_{B2,0}$	[0.2;0.4]	with $\mu_{B2,0} = 1 - \mu_{B1,0}$

SAMENVATTING

(Summary in Dutch)

Centraal in dit proefschrift stond het ontwerpen van een theoretisch en mathematisch model om sociale interactie en risicogedrag bij adolescenten te analyseren uitgaande van de principes van de complexe dynamische systeem theorie. Meer in het bijzonder was het hoofddoel van dit proefschrift gericht op het onderzoeken van hoe de dynamische effecten van invloeden en selectiemechanismen in de omgang met leeftijdgenoten ("peers") – zowel op de korte als de lange termijn – van invloed zijn op diverse ontwikkelingsschalen.

Hoewel het theoretische en empirische gedachtegoed omtrent "peer" invloeden en "peer" selectie aan de basis heeft gestaan van het huidige proefschrift, is er weinig theorievorming over de vraag hoe "peer" invloeden en "peer" selectie veranderen in de loop van de tijd. Met dit proefschrift is getracht deze leemte in kennis aan te vullen door de bestaande theorieën te beschouwen vanuit het dynamische systeem (DS) perspectief. Het dynamische systeem theorema is bij uitstek geschikt gebleken voor het beschrijven van ontwikkelingsprocessen in de tijd (zowel op de korte als op de lange termijn), en daaraan gekoppeld de theorievorming over deze processen.

Een belangrijk voordeel van het toepassen van de DS is dat het je dwingt om de dynamische effecten van "peer" invloeden en "peer" selectie zo helder mogelijk te conceptualizeren, met een nadruk op het belang van hoe deze effecten veranderen in de tijd. Daarom was het nodig een zo gedetailleerd mogelijke theorie omtrent verandering te formuleren. Daartoe moesten niet alleen de hoofdkenmerken van de te modeleren processen sec maar ook hun onderlinge dynamische invloeden en verbindingen worden gedefinieerd. Met andere woorden er moesten regels (dynamische wetten) worden geformuleerd op basis waarvan de effecten van "peer" invloeden en "peer" selectie veranderen in de tijd. Het beginpunt van onze studie bestond uit het formuleren van onze hoofd (dynamische) vraag: *Hoe brengen enerzijds de korte-termijn interacties met vrienden veranderingen bij een adolescent teweeg, en hoe passen anderzijds die vrienden hun gedrag aan aan dat van de adolescent?*

Om bovenstaande vraag te beantwoorden kozen wij voor een multi-level aanpak (in de niet-statistische zin van het woord) die drie niveaus omvatte:

1) Het formuleren van een theoretisch raamwerk
2) Het omzetten van die theorie in een mathematisch model van het dynamische systeem
3) De validering van de theorie door middel van empirische data.

Het eerste deel van dit proefschrift is gewijd aan de formulering van een dynamische theorie omtrent interacties tussen vrienden en risicogedrag tijdens de adolescentie (hoofdstuk 2). De theorie was er op gericht om te verklaren hoe de korte-termijn en lange-termijn eigenschappen van "peer" invloeden en "peer" selectie verschillende en stabiele ontwikkelingsuitkomsten genereren, zoals vriendschappen en homogene (overeenkomende) risicogedragingen. Samenvattend, onze dynamische hypothese stelt dat: vriendschappen tussen adolescenten ontstaan onder invloed van wederzijdse gedragsprofielen (gelijkheid), voorkeuren en/of populariteit, en door wederzijdse beinvloeding dan wel bekrachtiging passen ze hun gedragingen (onder voorwaarde dat ze als positief worden gezien) op een dusdanige wijze aan dat hun gedragsprofielen meer gelijk worden, meer overeenkomst gaan vertonen. Indien daarentegen de adolescenten elkaar negatief waarderen, zullen hun interacties naar alle waarschijnlijkheid stoppen.

In de door ons gebruikte dynamische theorie is evaluatie een belangrijke voorwaarde om tot gedragsverandering te komen. Door evaluatie een dusdanig belangrijke rol toe te kennen in onze theorie, hebben wij de actieve rol die adolecenten hebben bij het kiezen, onderhouden en/of stoppen van hun vriendschappelijke banden willen benadrukken. Onze theorie stelt ook nadrukkelijk een onderscheid tussen invloeden en bekrachtiging voor. Er is sprake van invloeden als een adolescent een nieuwe gedraging overneemt (bijvoorbeeld roken) omdat een vriend dat gedrag laat zien. Van bekrachtiging, daarentegen, is sprake als beide vrienden de eerste aanzetten tot risicogedrag vertonen, en deze gedragingen verhevigen onder invloed van interacties met vrienden.

Het tweede deel van dit proefschrift is gewijd aan het ontwerpen van het dynamische systeem model. In hoofdstuk 3, beschrijven wij het model in mathematische termen. Het gepresenteerde model is een combinatie van een discreet dynamisch systeem model en een “agent based” model. Het model bestaat concreet uit een reeks van gekoppelde vergelijkingen en beslisregels die in een iteratief proces worden uitgevoerd. Het wordt geïmplementeerd in de vorm van een “Visual Basic for Applications” model (VB) en kan worden getoetst met Microsoft Excel. Concreet werden met behulp van Microsoft Excel theoretische eigenschappen omgezet in wiskundige matrixen en iteratieve bewerkingen van deze matrixen. Deze iteratieve bewerkingen simuleren de temporele aspecten van de hoofdthema’s die onderwerp van studie waren in dit proefschrift, te weten vriendschappen en risicogedragingen tijdens de adolescentie. Anders dan veelal het geval is bij statistische analyses, resulteert de modelmatige aanpak die in dit proefschrift is gekozen niet in een voorspelling van een factor (bijvoorbeeld de mate van risicogedrag van een adolescent) op basis van andere factoren (bijvoorbeeld de homogeniteit onder vrienden). In tegendeel, het model tracht door het gebruik van dynamische regels en non-lineaire interacties tussen haar eigenschappen te verklaren hoe homogeniteit ontstaat en zich ontwikkelt in de loop van de tijd. Samengevat, het model tracht het proces van verandering in de tijd te verklaren.

In hoofdstuk 4 wordt de werking van het model verklaard en geïllustreerd aan de hand van de diverse uitkomsten van het model (in de tijd). Het eerste gedeelte van de modelsimulatie heeft betrekking op het concept homogeniteit. De resultaten van de simulatie laten zien dat het model succesvol in staat is inzicht te geven in het ontstaan van vriendschap. De simulatie laat enerzijds zien hoe gelijkheid ontstaat door het naar elkaar toe bewegen van “agents” in de mathematische ruimte van eigenschappen, anderzijds laat het model afnemende gelijkheid zien wanneer “agents” zich van elkaar verwijderen. Het model laat ook zien dat er meer verandering in gedragsgelijkheid is aan het begin dan aan het eind van de simulatie. Het laatste deel van de simulatie had betrekking op de concepten invloed en bekrachtiging. De resultaten lieten zien dat het optreden van het “bekrachtigings” effect waarschijnlijker is dan het optreden van het “invloed” effect. Samengevat bleek uit de resultaten dat het model werkt en stabiel genoeg is om resultaten te genereren die in overeenstemming zijn met de bevindingen uit de literatuur.

In het laatste deel van het proefschrift worden de bevindingen uit de empirische studie gepresenteerd (hoofdstuk 5). Aangezien het hoofddoel van het proefschrift was te onderzoeken hoe gelijkheid verandert in de loop van de tijd, werden er vier meetpunten, verspreid over een jaar, gebruikt. De data werden verzameld met behulp van een vragenlijst. Om de ecologische validiteit te verbeteren werden er, naast gegevens omtrent netwerken van vrienden uit de klas van de ondervraagde, ook vriendschapsgegevens uit andere klasssen gebruikt. De empirische studie omvatte ook gegevens uit de overgangsfase waarin adolescenten van klas 2 naar klas 3 gingen (tussen meetpunt 1 en meetpunt 2). Bij deze overgang verandert de samenstelling van de klas nogal, en krijgen de leerlingen met nieuwe klasgenoten te maken. De bedoeling van het opnemen van die overgangsperiode in de studie was het creëren van een mogelijkheid om tussen "selectie-" en "invloed"effecten te kunnen onderscheiden. Immers op deze wijze konden er data worden verzameld van voor het ontstaan van de vriendschappen (eind van 2e jaar voortgezet onderwijs), en van na het ontstaan van vriendschappen (3e jaar van het voortgezet onderwijs).

In het eerste deel van de empirische studie werd onderzocht of en hoe gelijkheid verandert in de loop van tijd; meer in het bijzonder werd getracht de volgende vragen te beantwoorden: *Is er sprake van meer gelijkheid in gedrag tussen vrienden dan tussen niet-vrienden? Hoe verandert gelijkheid in de loop van een jaar?* Onze resultaten lieten zien dat er gemiddeld gesproken een grotere mate van gelijkheid bestaat tussen twee vrienden vergeleken met twee niet-vrienden. Bovendien bleek dat in de loop van de tijd gelijkheid eerst toeneemt en later afneemt. Samengevat werden deze bevindingen gezien als een bevestiging van de gelijkheidheidshypothese. Tevens bleek uit deze resultaten dat gelijkheid geen statisch fenomeen is dat stabiel blijft in de loop van de tijd. Integendeel, gelijkheid veranderde in de tijd volgens een omgekeerde U-curve: een toename rond het midden van het schooljaar, en een afname naarmate het einde van het schooljaar naderde, waarbij er sprake was van een uiteindelijke stabilisatie op een hoger niveau vergeleken met de start van het schooljaar.

Het tweede deel van de empirische studie richtte zich op de beantwoording van de volgende vragen: *Vertonen vrienden dezelfde soort gedragingen nog voor de tot standkoming van hun vriendschap?* Onder onze participanten, bevond zich een sub-groep van scholieren die nog geen vrienden waren op meetpunt 1, maar pas daarna op meetpunt 2 vriendschap hadden gesloten. Uit de resultaten bleek dat op meetpunt 1 de participanten die later vrienden zouden worden reeds dezelfde soorten risicogedrag vertoonden als op meetpunt 2 waar ze inmiddels vrienden waren geworden. We vonden echter ook een stel toekomstige vrienden die geen vergelijkbare gedragingen vertoonden op meetpunt 1. Het ontstaan van deze vriendschap werd gezien als mogelijk veroorzaakt door het "invloed" proces. De modelsimulatie model resulteerde in vergelijkbare bevindingen.

Zowel de empirische studie als de modelsimulatie bevestigden dat ter verklaring van het ontstaan van "peer"groepsvorming meer variabelen van belang zijn dan alleen "invloed" variabelen. Adolescenten worden niet willoos gedwongen om gedragingen die ze niet wensen van elkaar over te nemen, of anderszins om vriendschappen te sluiten met leeftijdsgenoten die ze niet respecteren. Ze kiezen daarentegen actief hun vriendschappen op basis van persoonlijke voorkeuren. Uiteraard dient hier te worden vastgesteld dat uit deze studie niet kan worden geconcludeerd dat adolescenten "risico" vriendschappen zouden moeten aangaan, of dat het 'vrij' kiezen van een risicovolle vriendschap een juiste beslissing zou zijn. De slotsom van dit proefschrift luidt daarom dan ook dat vriendschappelijke interacties en “peer” invloeden complexe fenomenen zijn die onder invloed van diverse in de loop van de tijd veranderende aspecten tot stand komen, waarbij er uiteindelijk nieuwe evenwichtssituaties zullen gaan ontstaan. Deze dynamische processen dienen bij voorkeur te worden onderzocht met behulp van (dynamische) procesgeoriënteerde onderzoeksmethodes.

ACKNOWLEDGEMENTS

Friends were not only the subject of this dissertation but also an essential part of its realization. I consider friends very important in my life and I believe that without the support of many friends and colleagues this thesis would not have come to an end. Therefore, it is now time to thank them!

First of all, I would like to thank my promoter Prof. Paul van Geert and my co-promoter Dr. Harke Bosma. Paul, the first time I read an article about the dynamic systems approach, it was so fascinating. Although I was not very familiar with the material, something was telling me it was right! The dynamic systems approach and the way you have taught me about developmental psychology convinced me to accept the project. When I first arrived in Groningen as an exchange student, I could never have imagined that I would end up building a dynamic systems mathematical model. It was a big challenge for me, and if I was able to accomplish it, I have to thank your great teaching skills, the passion you have for your work and your great sense of humor. It has been a pleasure and a strong inspiration to work with you. Thank you so much for your outstanding support.

Harke, you believed in me since the beginning. With you I did not only spend time working, commenting and correcting the thesis but I also shared many personal stories including difficulties and crisis. When I had some moments of doubts about the research, you were always there with positive and encouraging words. This emotional support has been essential for me. But I also thank you very much for all I learned from you! It was a great honor and pleasure to work with you!

Secondly, I would like to thank Prof. Rutger Engels, Prof. Isabel Granic and Prof. Geertje Timmerman for agreeing to be part of the reading committee. Thank you for all the time spent reading and evaluating my thesis. Rutger and Isabel you were also a great source of inspiration for the thesis. Reading your articles and sharing research ideas with you I learned new ways of thinking about adolescence development.

I'm also very grateful for the advice I received from Prof. Tom Snijders and Dr. Bill Burk about social network modeling. Thank you for your great help. When I went to the United States to learn about new methods for studying friendship interactions, I had a wonderful and rewarding learning experience. For this, I want to thank Prof. Tom Dishion.

A owe a very special thank you to Nils Schuhmacher. I'm very grateful you have agreed to help me building the mathematical model. We had a great and efficient collaboration. During your visit to Groningen we didn't only work well together at the model but we also had good time.

I also would like to thank the school management of the Ubbo Emmius school community in Winschoten, the school psychologist Marjan Adema, all the teachers and mostly all the adolescents who took part in the research. I really enjoyed the time spent at the school. I'm also very grateful for the psychology students who were involved in the research for helping me with the data collection and analysis. Thank you Alitha,Corina, Ilva, Kim, Marlene and Karin.

Two people deserve a very special thanks since they did not only help me academically but also were crucial in my personal development. One of these is my special friend: Peter Hendriks. Peter you are the reason why I decided to spend my life in Holland, you are the reason why I had the courage to accept the offer of the PhD position. During the many years spent together you were not only a great partner and friend but also a great teacher. Thank you so much to have been always there for me, even when our relationship became difficult. I know you did not always accept my personal choices but you have always accepted me as a good and real friend should do. Thank you very much!

My second special thanks goes to my best friend, former colleague and officemate Anna Lichtwarck-Aschoff. Anna, the time spent with you during the PhD years was amazing. I enjoyed our time together very much, our discussions about our projects, but also about life, all the conferences and workshops that we attended together. I'm happy our friendship is still solid although our work and personal situations took us in different directions. Thank you to be my friend, sweetie!

Other colleagues have made the time spent at the developmental psychology department very pleasant and deserve many thanks! Marieke V. you are a very sweet and nice person; thank you for being there for me when I needed to talk with someone about personal or job stuff. Thank you to understand the different background I'm coming from and to adjust to my Italian way of doing and saying things. Marieke B. and Els, thank you for the nice time spent together during dinners, coffee and tea breaks, photos and vacations time. I hope we will continue to be in contact. A big thanks goes to the other PhD students of the developmental psychology department Koen, Georgios, Daan, Marijn, Sabine, Henderien, Raphaele, Annemieke, Jessica and Baukje. We had a very nice time together. I will always remember you with joy! I also would like to thank the staff of the department Saskia, Gerritt, Reint, Anke, Matty and Philippa for sharing ideas and commenting the thesis. Of course, I would like to thank the lovely secretaries Wolly, Fenna, Josje and Lucia for your great support! You always had a big smile for me when I was entering your office. Thank you!

A special thanks goes also to my new colleagues of the A3O department! Guys, you are all just great! I have such pleasant time going to work and our "archive" pauses are very special! A special thanks goes to Rob who gave me the time and the space to finish this thesis and the academic advisers: Berber, Sietske and Libbe. You are very nice colleagues. Libbe thank you for the translation of the Dutch summary. Always ready to share a glass of good wine with you! Berber thank you for the beautiful drawing for the book cover. Thanks also to Edwin Kiers for his technical help with the setup of the online questionnaire! Last but not least, I would like to thank Alette and Dinie. You have both become very closed friends and I'm so happy I can share not only work related issues with you but also my daily routine! I hope our friendship will last for long! Dinie you have been a great paranimf and friend: always there for me! Thank you so much!

I also would like to thank my friends: Cristina, Hansje, Simona, Donald, Ariane, Fioly, Fabio and Sara. Just thank you to be there when I need your support and for all the fun we have together! You are wonderful friends! Sara grazie per aver fatto un bellissimo lavoro con l' impaginazione del libro. E' bellissimo!

Naturalmente un grandissimo grazie va alla mia famiglia. Mamma e papa' voi mi siete stati sempre al fianco e mi avete sempre incoraggiato nelle mie scelte. So che non e'stato facile lasciarmi andare a vivere in un paese cosi lontano, ma so anche che adesso siete tanti orgogliosi di me. Mamma non puoi immaginare come sono felice che tu abbia visto la fine di questo lavoro. Sei una mamma dolcissima che mi ha insegnato tanto, soprattutto il valore della tolleranza e dello studio che mi hanno molto aiutato nel concludere la tesi. Papa' anche se non lo sai ammettere so che sei tanto orgoglioso di me. Grazie per avermi insegnato a lavorare duro e a dare sempre il meglio di me e grazie per esserci sempre quando ne ho bisogno! Un altro caro grazie va a mio fratello Giuseppe e alla sua compagna e anche amica Patrizia. Mi siete stati sempre vicini e mi avete sempre incoraggiato a non abbandare la ricerca quando non ero piu' sicura di farcela. Giuseppe sei stato la mia piu' grande influenza intel-letuale e di studio della mia vita. Se sono arrivata fino a qui è anche merito tuo!

A very special thanks goes to my partner Owen Hart Jr. Although we do not share the same work passion, we have learned to appreciate our different talents and we have found a way to help each other! You have been also a great practical help by taking care so well of our house and our children. But most of all thank you for understanding my bad mood and tiredness and to let me be who I'm! Lastly, thank you for all the great music you have brought into my life!

Lastly, I have to thank my two little boys David and Leonard. You are the most positive influence I have ever received from another human being! You made me a better and strong person. I love you very much!

CURRICULUM VITAE

Laura Ballato was born on the 12th of June 1972 in Turin (Italy). After receiving her high school diploma from the Gymnasium School of Chivasso (Italy), she studied Psychology at the University of Turin (Italy). During her university years she worked at the Psychiatric Hospital of Turin and helped with psychodiagnostics assessments and psychological tests of developmental disorders. In October 1999, she participated in the Socrates European Exchanging Program and moved one year to Groningen, the Netherlands. After her graduation, she moved back to Groningen for a research internship. In 2003, she started her PhD on the development of risk behaviors and friendship interactions during adolescence at the Department of Developmental Psychology of the University of Groningen from which she received a grant from the Ubbo Emmius foundation. She is a member of the Dutch research school ISED (Institute of the Study of Education and Human Development) and the EARA (European Association for Research in Adolescence).

Since September 2008, she is working as an academic adviser at the Department of Psychology of the University of Groningen.

Publication:

Molinar, R., Ciairano, S., Bonino, S., Ballato, L., & Barbareschi, G. (2004). Il ruolo dell'esperienza scolastica nell'uso di sostanze psicoattive: una ricerca longitudinale e cross-nazionale. *Psicologia della Salute*, 3, 53-70.

In preparation:

Ballato, L., van Geert, P., & Schumacher, N. (2012). A dynamic systems model of friendship interactions and risk behaviors during adolescence.

Ballato, L., Bosma, H.A. & van Geert, P. (2012). A longitudinal study of friendship interactions and risk behaviors during adolescence: Bridging empirical and simulation results.

Presentations:

09/2002: A cross-cultural and longitudinal research concerning the involvement in risk behavior of Italian and Dutch adolescents: the moderating role of the school. *Poster presentation at the National Conference of the AIP (Associazione Italiana di Psicologia) Bellaria, Italy.*

05/2004: Adolescents, peers and risk taking: A dynamic systems perspective. *Poster presentation at the EARA, Porto, Portugal*

08/2005: Adolescents, peers and risk taking: A dynamic systems perspective. *Invited paper presentation at the European Society for Developmental Psychology (ESPD), Tenerife, Spain*

05/2006: The dynamics of selection and influence processes in peers interactions: A dynamic systems perspective. *Invited paper presentation at the EARA, Antalya, Turkey*

08/2007: Zooming in on adolescents social interactions: A dynamic systems model of selection and influence processes. *Invited paper presentation at the European Society for Developmental Psychology (ESPD), Jena, Germany*

05/2008: A dynamic systems model of adolescents' social interactions and risk behaviors trajectories: Bridging simulation and empirical results. *Organization of paper symposium and paper presentation at the EARA, Turin, Italy*

The main aim of the present thesis is to build a theoretical and mathematical model of social interactions and risk behaviors during adolescence based on the perspective of complex dynamic systems. By using computer simulations, the model explicates the complex process of friendship formation and behavior transformation on different developmental time scales (e.g., here-and-now versus months and years). The central questions of the thesis are: How do friends promote changes in adolescents' attitudes during short-term interactions and over time co-adopt their own behaviors towards the ones of their friends? To answer our questions we apply three levels of analysis: Theoretical, mathematical and empirical. In the first part of the thesis, we propose a dynamic systems theory of friendship interactions and risk behaviors during adolescence. In the second part, we translate the theoretical framework into mathematical equations and present the results of the model's simulations, aimed at testing our hypotheses. In the last part of the thesis, the results of the empirical study are presented. The empirical study has two aims: First investigating whether similarity changes over time and second to differentiate between influence and reinforcement.