

Chapter 12

Analyzing Teacher–Student Interactions with State Space Grids

Helena J.M. Pennings and Tim Mainhard

Introduction

In educational research there is a growing body of knowledge on the general classroom and teacher characteristics that enhance or hamper student learning. This body of knowledge is primarily based on a product oriented research approach (Lavelli, Pantoja, Hsu, Messinger, & Fogel, 2005), that is, relying on global perceptions and measures, which summarize any development, rather than focusing on how classroom processes unfold in time. Another, more process oriented focus, may be more suited to understand how classroom interventions or specific teacher behavior take their effect in class during teaching. In this chapter we describe how we use a research tool called State Space Grid analysis, originated in Complex Dynamic Systems theory, to take a more process oriented rather than product oriented approach.

Our research mainly focuses on interpersonal teacher behavior and teacher–student interactions as the building blocks of teacher–student relationships and the quality of the classroom social climate. In this chapter we present four illustrations of studies that share this focus and in which State Space Grid analysis was used to examine the moment-to-moment nature of classroom interactions. First, interpersonal theory is introduced, which we use to frame classroom interaction. Then we discuss classrooms as complex dynamical systems and introduce the State Space Grid technique.

H.J.M. Pennings (✉) • T. Mainhard
Department of Education, Utrecht University, The Netherlands, Heidelberglaan 1,
80140, 3508, TC, Utrecht, Netherland
e-mail: h.j.m.pennings@uu.nl

An Interpersonal Perspective on Classroom Social Processes

The classroom social climate is the social aspect of the classroom environment; In product oriented terms, it refers to the overall quality of interpersonal relations in a classroom (Mainhard, Pennings, Wubbels, & Brekelmans, 2012). These relations can be conceptualized in terms of the generalized interpersonal meaning students and teachers attach to their own and each other's behavior in class. The basic processes that underlie the classroom social climate are virtually all interactions that occur in a classroom.

To describe interactions between teachers and students (or classes of students), we use Interpersonal Theory (Horowitz & Strack, 2011). In interpersonal theory a two-dimensional circular model called the *InterPersonal Circle* (IPC) is used to describe interpersonal styles and interpersonal behavior of people (Fournier, Moskowitz, & Zuroff, 2011; Gurtman, 2009; Horowitz & Strack, 2011; Kiesler, 1996). The basic premise of this theory is that every behavior can be positioned in the IPC as a specific blend of the two dimensions *agency* (i.e., power) and *communion* (i.e., warmth) (Fournier et al., 2011; Locke & Sadler, 2007). In essence an IPC always consists of the two basic dimensions, however how these dimension are called may vary depending on the context in which the model is applied (Fournier et al., 2011). The IPC can be divided into octants that describe prototypical interpersonal behavior located in that part of the IPC.

To study interpersonal behavior of teachers and students we use two IPCs (Fig. 12.1), one to describe interpersonal teacher behavior, the *IPC-T*, and one to describe interpersonal student behavior, the *IPC-S* (Pennings, Mainhard, & Brekelmans, 2015; Prins & Mainhard, 2012).

For decades interpersonal theory has been used in educational research to study the quality of the classroom social climate (for an overview see Wubbels,

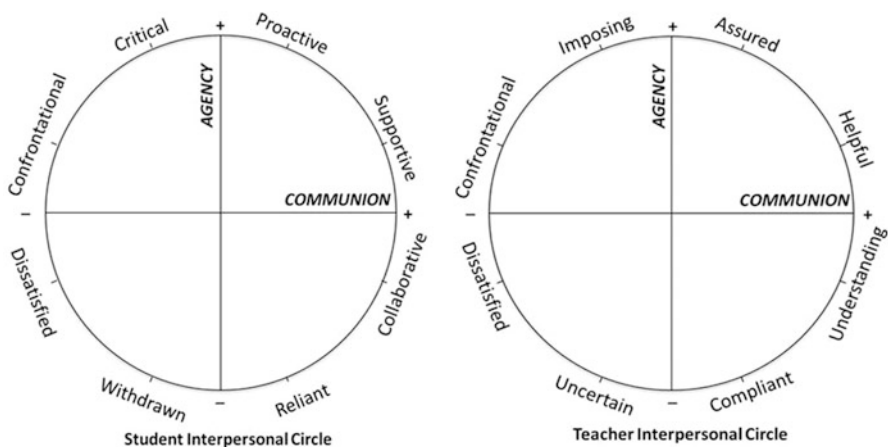


Fig. 12.1 Teacher and student interpersonal circle (Pennings et al., 2015; Prins & Mainhard, 2012)

Brekelmans, Den Brok, & Van Tartwijk, 2006), mainly through the applications of the Questionnaire on Teacher Interaction (QTI; Wubbels et al., 2006), which measures teacher agency and communion as perceived by students. By completing the QTI, students provide their general interpersonal perception of their teacher in class. To describe the general classroom social climate the individual student scores can be aggregated per class or teacher (Wubbels et al., 2006). Throughout the years nine general types of classroom social climates have been distinguished (Pennings et al., 2015). Eight types correspond to the IPC octants and the ninth is located in the center of the IPC.

Throughout the years ample knowledge has been gathered on how the quality of the classroom social climate, also from perspectives other than interpersonal theory, is related to student motivation and achievement (e.g., Cornelius-White, 2007; Henderson, 1995; Henderson & Fisher, 2008; Maulana, Opendakker, Den Brok, & Bosker, 2011; Roorda, Koomen, Spilt, & Oort, 2011; Wentzel, 2012), but also to teacher motivation, self-efficacy, well-being and quality of teaching (e.g., Spilt, Koomen, & Thijs, 2011; Van Petegem, Creemers, Rossel, & Aelterman, 2005; Wubbels et al., 2014). For example, classroom social climates that are characterized by high levels of agency and communion in teacher behavior are most desirable for student motivation and achievement, but also for teacher well-being (Wubbels et al., 2006). A problematic classroom social climate is often related to classroom management issues (Mainhard, Brekelmans, & Wubbels, 2011) and can even be a reason for teachers to leave the profession (De Jong, Van Tartwijk, Verloop, Veldman, & Wubbels, 2012).

Since, daily interactions are the building blocks of relationships (Granic & Hollenstein, 2003), many scholars, including Kiesler (1996), Thomas, Hopwood, Woody, Ethier, and Sadler (2014) and Wubbels et al. (2012), advocate to study the dynamical process of interpersonal interactions as they unfold in time instead of focusing solely on the static products of these interactions (such as the quality of the classroom social climate). Ultimately, doing so might help us to understand better how teachers who experience problems in creating and maintaining a classroom climate conducive to learning can be supported. The theoretical framework and its accompanying methods that guide us in this process oriented endeavor is Complex Dynamical Systems (CDS) theory.

Classrooms as Complex Dynamical Systems

CDS theory describes how complex processes unfold in time (Guastello, Koopmans, & Pincus, 2009), and how *change* occurs gradually or dramatically (Guastello & Liebovitch, 2009). CDS theory originates from physics and mathematics, where it is used to study complex processes within and between systems (Guastello et al., 2009; Hollenstein, 2013). For example in thermodynamics the study of how temperature and energy are related to each other can be explained using CDS theory. There are two types of systems, *closed* and *open* systems. Closed

systems are systems that cannot interact with other systems in its environment, whereas open systems develop through interactions with other systems in their environment (Hollenstein, 2013). Humans are open systems, because they interact with other systems in their environment, such as other humans or animals.

Interactions and development simultaneously take place on various time-scales. In real-time from second to second (i.e., micro-level time-scale), from hour to hour (i.e., meso-level time-scale), or in developmental time like month to month or year to year (i.e., macro-level time-scale) (Hollenstein, 2013). Development is, therefore, hierarchically nested in time (Hollenstein, 2007; Thelen & Smith, 1998). Defining the specific measurement level needed depends on the research question and the phenomenon that is studied. What makes development complex is that interactions occur *within* time-scales but also *between* time-scales (Hollenstein, 2013) and that behavior on one time-scale may affect behavior on another. For example, friendly teacher behavior from moment-to-moment may result in a supportive and warm classroom climate (a higher level time-scale), which in turn makes disruptive student behavior less likely (the lower-level timescale).

We have described how humans are considered to be individual complex dynamic systems and that interactions between humans foster development of systems. In the educational context teachers and students resemble individual systems as well, while classrooms (or the classroom social climate) can be seen as higher order social systems in which multiple individual systems (i.e., teacher and students) interact with each other. Interactions and development within classrooms also occur on multiple time-scales, from second to second within lessons (micro-level), from lesson to lesson (meso-level), month to month (meso/macro-level), and in some cases from year to year (macro-level). To complicate this, all individual systems within a specific classroom social system are also individual systems within other social systems (e.g., other classrooms, families, and sports teams). In these other social systems which different interactions might lead to differences in development of, for example, relationships (Bronfenbrenner & Morris, 2006). For teachers, this means that experiences in one classroom may transfer to other classrooms, also in subsequent years. Guided by CDS theory, we assume that these interactions are necessary for teachers to improve in their profession and that they drive teacher professional development.

To understand the illustrations of our research we provide in this chapter, it is necessary to grasp the meaning of several terms that are commonly used in CDS theory; terms such as state(s), state space, attractors, circular causality, and entropy. We elaborate on these terms in the next section. For a complete and comprehensive overview of these concepts and the CDS terminology we refer the reader to Guastello et al. (2009).

Using State Space Grids in Educational Research

Now that we have explained the two main theoretical perspectives that guide our research we turn to State Space Grid (SSG) analysis, which is the focus of the remainder of this chapter. The SSG tool is rooted in CDS theory and is used to examine the *content* (e.g., the level of friendliness) and *structure* (e.g., the variability in friendliness) of real-time (micro-level) interactions in systems. SSG studies can be found in various areas of social sciences research, such as family studies (e.g., Granic, Hollenstein, Dishion, & Patterson, 2003) where they originated, peer relationship studies (e.g., Lavictoire, Snyder, Stoolmiller, & Hollenstein, 2012), studies on cognitive styles in solving jigsaw puzzles (e.g., Hong, Hwang, Tam, Lai, & Liu, 2012), coach–athlete interactions (e.g., Turnidge, Cote, Hollenstein, & Deakin, 2013), or clinical psychology (e.g., Bento, Ribeiro, Salgado, Mendes, & Gonçalves, 2014). The last couple of years SSG analysis has found its way into educational research (e.g., Mainhard et al., 2012; Pennings, Brekelmans et al., 2014; Turner, Christensen, Kackar-Cam, Trucano, & Fulmer, 2014; Vauras, Kinnunen, Kajamies, & Lehtinen, 2013).

First, we explain what SSGs are; second, we discuss the measures that can be derived from SSG analysis; third, we describe how attractors and information about the structure of interactions can be derived from these measures; and finally we provide some illustrations from our own research in which we used various approaches to construct and use SSGs to study real-time interactional processes in class.

In 1999 Lewis, Lamey, and Douglas developed SSG analysis (Fig. 12.2) and GridWare (www.statespacegrids.org; Lamey, Hollenstein, Lewis, & Granic, 2004) the software needed to build and analyze SSGs, because they needed methods to study complex dynamical processes in child parent interactions (Hollenstein, 2013). In this chapter we largely draw on ideas and research that originated from this group and specifically on the Gridware manual (Lamey et al., 2004) and Hollenstein’s book on SSG analysis (Hollenstein, 2013).

The foundation of SSG analysis lies within the CDS term *State Space*. A SSG is a graphic representation of a state space that consist of at least two orthogonal dimensions that describe the states a system might reside in and all possible states a social system can adopt are graphically represented as cells in a grid. Hence, these cells together represent the state space of a social system. Thereby, SSGs provide an intuitively appealing way to view the structure of complex interactional, which makes SSGs also very suitable for exploratory analysis (Granic & Hollenstein, 2003; Hollenstein, 2013).

The dimensions underlying the SSGs usually consist of categorical observations of behavior states. It is important that these categories are mutually exclusive and exhaustive on each dimension (Granic & Hollenstein, 2003; Hollenstein, 2013; Hollenstein & Lewis, 2006). For example, in our studies one dimension may represent interpersonal teacher behavior, while the other represents interpersonal student behavior. Yet the dimensions and the number of categories underlying the dimensions need not to be similar (Hollenstein, 2013). For example, in one of our

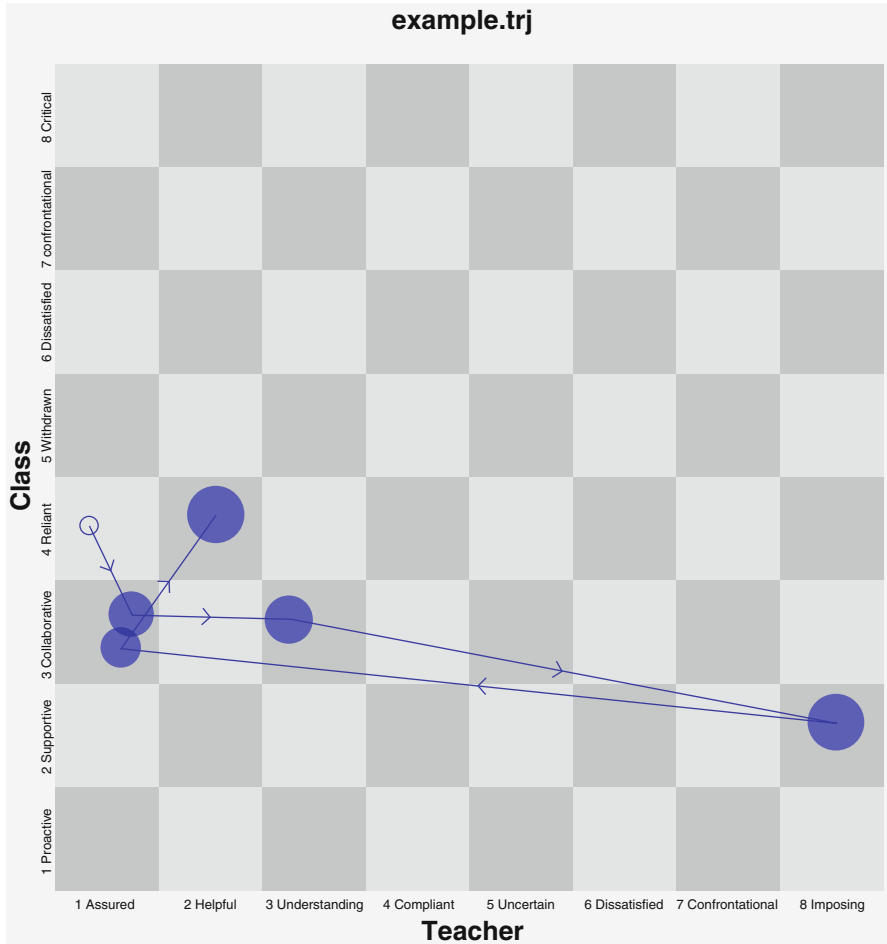


Fig. 12.2 Example of a state space grid of teacher–class interaction. *Note.* The horizontal axis shows the teacher’s behavior and the vertical axis the class’s behavior. The *arrowed line* represents the change in behavior in the interaction over the course of a few minutes (i.e., the interaction trajectory), and the thickness of the nodes indicates the duration of each interaction state. Note that the position of a node in a cell is arbitrary. The *opaque node* marks the start of the interaction

first studies (Pennings, Van Tartwijk, Vermunt, & Brekelmans, 2012) we combined eight categories of interpersonal teacher behavior (i.e., the categories reflect the octants of the IPC-T) with four categories of student behavioral engagement (i.e., passive/active on-task or off-task behavior; see Illustration 4).

In several studies (i.e., Mainhard et al., 2012; Pennings et al., 2015; Pennings, Van Tartwijk et al., 2014) the state space of teacher and class behavior is comprised of all the possible joint states of agency and communion that teachers and students might adopt in interaction. Thus, in these studies every cell in the SSG represents a specific *dyadic* state, that is a typical combination of the interpersonal behaviors the

teacher and the class show at a certain moment during the lesson. Every time the behavior of the teacher or the class changes a new event occurs and a new point is plotted in a SSG cell (i.e., the dyadic state changes), this is often referred to as online or real-time coding. In this way all changes in level of agency/communion in both teacher and student behavior are visualized as a change in the interaction trajectory within the SSG.

In order to explain how a SSG is used as a visual representation of a given interaction an example SSG is included in Fig. 12.2. Note that this SSG represents a fictional trajectory of classroom interaction.

The state space in Fig. 12.2 consists of an 8×8 grid. Teacher behavior is displayed on the x -axis and student behavior on the y -axis. The eight categories correspond to the octants of the IPC-T and IPC-S. Therefore each cell in the grid represents the intersection of interpersonal teacher behavior and interpersonal student behavior observed in the students. For the analysis it is arbitrary on which axis whose behavior is displayed.

When a particular combination of behavior, let us say teacher assured behavior and student reliant behavior, is observed at a given point in time a so-called *node* is drawn in the corresponding cell. Teacher assured behavior corresponds to the first cell on the x -axis, thus $x1$, and student reliant behavior corresponds to fourth cell on the y -axis, the $y4$. To refer to a specific cell we follow xy convention, and thus this cell is called 14.

The start of the interaction can be marked with a hollow node. In this example the interaction starts in cell 14. Let us say that this state reflects a lecturing situation where students listen rather quietly to what the teacher says. Then, some students start to chat unvoiced with each other, and the level of agency in their behavior increases; the interaction trajectory thus moves to cell 13. Next the teacher may notice that some students chat, but lets the students talk for a while and thus the level of agency in the teacher's behavior decreases and the trajectory moves to cell 33. The students' talk becomes louder and more engaged, and after a while the teacher restricts the students, that is, the teacher's level of agency increases and the level of communion decreases and thus the trajectory moves to cell 82. In this hypothetical scenario, the students react to the teachers' imposing behavior and their behavior becomes more collaborative and eventually reliant again and at the same time the teacher becomes assured and eventually helpful, and the teacher resumes her lecture in an assured manner. Thus from cell 82 the trajectory moves to cell 13 and eventually to cell 24. To visualize how the observed interactional trajectory changes chronologically in time, it is possible to add a line that connects the nodes in the SSG. For the purpose of clarity we also added arrows to the line in this example SSG. The combination of these nodes and lines is called the interaction trajectory.

It is important to note that the interpretation of the observed behaviors in each cell entirely depends on the observational system used. In most of our own studies the unit of analysis represented in the SSGs is the dyadic behavior of teachers and students in moment-to-moment interactions. To study patterns in these interactions Granic and Hollenstein (2003) recommend looking at the content and structure of interaction.

Content of Interaction

The locations of attractors (a single cell or several adjacent cells) provide information about the *content* of the micro-level interactions as they indicate *what* states occur most frequently (Granic & Hollenstein, 2003; Hollenstein & Lewis, 2006), for example mutually friendly behavior. As specific interactional patterns between teacher and students become apparent (i.e., attractors emerge), the macro-level classroom social climate may become more constrained and defined. For example, a poorly organized classroom lesson might evoke distraction and chatting amongst students, which in turn may lead to dissatisfied teacher behavior; the more often lessons are poorly organized, the more easily students may become distracted, and the more easily aversive teacher behavior may be triggered, i.e., a negative interaction attractor develops (see for an example from teacher practice Créton, Wubbels, & Hooymayers, 1989). Moreover, an attractor may become stronger through *feedback loops* and *circular causality* between those negative interactions on the micro-level time-scale and the poor classroom social climate on the macro-level time-scale. Such processes could explain why in classrooms with less positive social climates even minor student misbehavior may trigger repressive teacher reactions with a high intensity (Créton et al., 1989). On the other hand, a teacher that introduces project based work in class for the first time may struggle to structure and support student activities. Students however may get engaged by this kind of work and may be more responsive to the teacher's efforts the next time project based assignments are used. An, in interpersonal terms, positive (i.e., mutually warm or communal) interaction attractor emerges. In more positive classrooms, corrections with a low intensity may be sufficient to return students' attention to class related activities (Wubbels et al., 2006). Indeed, such processes of stabilization seem to occur within only one or just a few lessons (Mainhard, Brekelmans, den Brok, & Wubbels, 2011).

Based on how long interactional behavior is located in a particular cell or cell region attractors and their strength can be identified. Hollenstein (2013) explains several methods to identify attractors in detail; some methods are more rigorous than others. It is for example possible to select the cell or cells with (a) the highest mean durations, (b) the highest total duration, or (c) the highest number of visits as attractors (Hollenstein, 2013). It is also possible that, based on theory, the researcher has defined an attractor or attractor region beforehand. One may then calculate a measure called *perseverance*, the mean duration that interaction remains in that specific state. A higher value for a cell represents a stronger perseverance. It is also possible to calculate perseverance for a specified area in the SSG, which is defined by the researcher (see Illustration 1). Yet a more empirical procedure to identify attractors is the *Winnowing procedure* (Lewis, Lamey, & Douglas, 1999). Using this method, the cell or cell region with the highest probability of being an attractor is identified based on a heterogeneity criterion. This procedure iteratively (step-by-step) eliminates the cells with the lowest durations (i.e., perseverance). Then a heterogeneity score is calculated using the following formula:

$$\text{Heterogeneity}_j = \frac{\sum (\text{Observed}_i - \text{Expected}_j)^2 / \text{Expected}_j}{\# \text{ of Cells}_j}$$

where i represents the specific cell targeted in iteration j . The observed value is the duration that the interaction trajectory resided in the target cell. The expected value in each cell is calculated by the total duration of the observed interaction divided by the number of cells included in the iteration.

The heterogeneity scores corresponding to each cell are quantified as a proportion of the heterogeneity score in the first iteration by dividing heterogeneity_j by heterogeneity_i . The value after the largest drop in proportions (i.e., Lewis et al., 1999 defined large as $\geq 50\%$) indicates that the target cell in that iteration may be regarded as an attractor cell (Hollenstein, 2013). If multiple adjacent cells are turn out to be attractors, this can be referred to as an attractor region. Please refer to Hollenstein (2013) who describes this procedure in a comprehensible and straightforward way.

Thus, with SSGs it is possible to identify attractors by tracking how long interactions remain in some states but not others or how quickly interaction returns to or stabilizes in particular states (Granic & Hollenstein, 2003). However, an interaction often does not remain in only one state, even though that one state might be an attractor. It is therefore also possible to study changes from state to state, how often these occur and how predictable these state-to-state changes are. These changes are what Granic and Hollenstein (2003) refer to as *structure*.

Structure of Interaction

An interaction trajectory may remain in one or a few states for a large part of the time, which would indicate a stable or inflexible system. On the other hand, if the dyadic trajectory includes many different states and there are a lot of state-to-state changes, that indicates a more chaotic or flexible system (Granic & Hollenstein, 2003). The terms someone chooses to describe the degree of variability (flexible versus chaotic) ultimately depends on external criteria. Because it has been found that in Mother-child interactions variability is positively associated with the child's social adjustment later, Granic and Hollenstein (2003) used the more positive term "flexible." In the classroom, however, higher variability in teacher behavior or teacher–student interactions is associated with less desirable classroom social climates (i.e., in terms of learning outcomes), and therefore, Mainhard et al. (2012) used the term "chaotic" rather than flexible to describe highly variable systems.

Gridware (Hollenstein, 2013; Lamey et al., 2004) provides several so-called whole-grid measures to study variability or the structure of interaction. In our own research (Claessens et al., 2014; Mainhard et al., 2012; Pennings, Brekelmans et al.,

2014; Pennings, Van Tartwijk et al., 2014) we have used the following grid measures: (1) the number of uniquely visited cells (i.e., cell range), (2) total cell transitions (i.e., number of visits or state-to-state changes), (3) the average duration per cell, (4) the average duration per visit, (5) dispersion, and (6) visit entropy. Before turning to a more detailed description of our own work, we first provide a more general explanation of these whole-grid measures. All these measures are related as they all tap the structure of a trajectory, but each concerns a specific aspect of how interaction moves across the state space.

The two measures *number of events* and *number of visits* may seem similar, but can yield very different figures. The *number of events* corresponds to the number of nodes in the SSG whereas the *number of visits* is the number of nodes transitioning to a new cell. In our example in Fig. 12.2 the number of events and the number of visits are both 6. In some studies it is possible that there is a change in behavior observed and is counted as another event, but that event remains in the same cell. This is completely dependent on the observation method and scheme used.

The *number of unique cells visited* (i.e., cell range) is the number of unique behavioral states that occur in an interaction trajectory. The example SSG provided in Fig. 12.2 consists of 64 cells (i.e., based on the octants in the IPC-T and IPC-S) and the interaction moved between only 5 out of these 64 cells, then the number of unique cells visited is 5. Of course it is likely that some cells are visited multiple times by an interaction-trajectory, in the example SSG there was one cell that was visited twice. A higher value is one indicator of more variability in the interaction.

Total cell transitions (TCT) is the number of movements between cells. *TCT* is calculated as the *number of visits*—1 (i.e., the first visit is not counted as a transition). A lower value indicates less frequent changes of system states, and therefore less variability. *TCT* may be high while the number of unique visited cells is low. In our example in Fig. 12.2 *TCT* is 5 (6 cells—1).

The *average duration of visits* is the duration of the observed interaction trajectory divided by the *number of visits*. The *average duration of visits* indicates the overall variability of behavior, which Hollenstein (2013) calls “the overall stuckness or rigidity of the trajectory” (p. 72). When the interaction trajectory during the observed period remains in one specific cell (i.e., the *number of visits* is low), the average duration of visits is extremely high (i.e., the average duration equals the total duration of the interaction). When the interaction trajectory continuously switches from one cell to another (i.e., the *number of visits* is high), the average duration of visits is low.

The *Average duration per visited cell* is the duration of the observed interaction trajectory divided by the number of uniquely visited cells (rather than total visits, see above). When the interaction trajectory during the observed period remains in one specific cell (i.e., the *cell range* is low), the *average duration per visited cell* will be extremely high, then the average duration equals the total duration of the observation period. Also, note that if multiple events within that single cell occur, the *average duration per visited cell* remains the same. When the interaction trajectory continuously switches from one cell to other cells (i.e., the *cell range* is high), the *average duration per cell* is low.

Dispersion describes the extent to which interactional states are scattered across the state space. This measure is based on the *number of visited cells* while controlling for the proportional *average duration per cell*. It is calculated by taking the sum of the squared proportional average duration per cell across all visited cells corrected for the total number of cells and inverted (Hollenstein, 2013). Thus, dispersion is expressed in a value between 0 (no variability) and 1 (maximum variability).

Visit entropy represents the degree of predictability of an interaction trajectory. It is calculated by summarizing the conditional probabilities of cell visits (Dishion, Nelson, Winter, & Bullock, 2004; Hollenstein, 2013) in order to do so the Shannon and Weaver (1949) formula¹ for entropy was built into GridWare (Dishion et al., 2004; Hollenstein, 2013). When visit entropy is high, the system's behavior changes frequently between many cells, indicating that the pattern of interaction is unpredictable. Low visit entropy means behavior remains in only a few states, returns to the same states often, or constantly visits a few states in the same order; this indicates a highly organized and predictable pattern of interaction (Dishion et al., 2004; Hollenstein, 2013; Lunkenheimer & Dishion, 2009).

Areas of Interest and Specific Cells

In some cases researchers may study predefined grid regions, or *areas of interest*, which can be based on theory or previous studies. For example, with regard to the most desirable classroom social climate, we know that assured and helpful teacher behavior in combination with reliant and collaborative student behavior is good for learning outcomes and a positive social climate (Wubbels et al., 2006). We could therefore, define a specific area in the grid and study to what extent the teacher–class interaction trajectories visit this specific area. To study such areas of interest Gridware (Lamey et al., 2004) allows selecting specific cells or cell regions of the SSG, which makes it possible to derive several measures related to those specific cells or the cell region. These measures are called *cell or region measures* (Granic & Hollenstein, 2003). We have already explained some of these measures, such as *perseverance*, because this measure is needed to identify attractors with the winnowing procedure. Remember that *perseverance* is the mean duration an interaction remains in a specific cell. It is however also possible to select multiple cells and to calculate the *perseverance* within that entire grid area. Another *cell or region* measure is the *return latency*. *Return latency* equals the time it takes before an interaction returns to a specific cell or area of interest and is an additional measure

¹ The Shannon and Weaver (1949) formula for entropy that is built into Gridware to calculate visit entropy: $\sum(P_i \times \ln(1/P_i))$. In which i is an index of each cell on the grid and P_i is the probability in cell i . Thus, for visit entropy, P_i is the number of visits to cell i divided by the total number of visits in the entire trajectory.

for the strength of an attractor. A lower *return latency* indicates a stronger attractor and a high *return latency* may indicate a repeller (opposite of attractor) or weak attractor. A return is defined as a sequence of events starting with the exit from the cell or region and ending with the return to the cell or cell region. The duration of this sequence is the *return latency*. For example, the interaction in a disorderly classroom may be mutual positive at times, but with long intermediate states including unfriendly behavior. This would result in relatively long return latencies for more positive interpersonal states (e.g., friendly behavior) or areas of interest.

Applications of SSG to Study Interpersonal Processes in Classrooms

In this section we provide some examples of how we used SSGs in our research focusing on classroom interaction. We present four illustrations of how we used SSGs and in each example we first sketch the question of the specific study and explain the global method that was followed. Across the studies different types of state spaces have been built, which are explained for each illustration separately. It is also explained which grid measures were chosen and finally, the general conclusion of each study is summarized. The illustrations discussed are all based on research in Dutch secondary education classrooms.

The illustrations we provide focus on how teacher behavior (an intra-personal process) or teacher–student interaction (a dyadic process), which occur in real-time, can be captured with SSGs. In Illustration 1, a specific area of interest, which was predefined to reflect more favorable teacher–student interaction, was used to facilitate the comparison of two classrooms taught by teachers with rather distinct classroom social climates. In this study three consecutive lessons were included. In Illustration 2 SSGs are used to plot *intrapersonal* processes, here the behavior of the teacher, in terms of agency and communion is examined to illustrate that it is also possible to study real-time processes within persons. In Illustration 3 we studied teacher–student interactions of 35 teachers during the lesson start and studied how content and structure of those interactions are related to the general classroom social climate. In Illustration 4 we looked at interpersonal teacher behavior and student behavioral engagement in four classrooms. In this study we also predefined an area of interest and sampled three classroom situations (i.e., lesson start, a positive interaction episode, and a negative episode).

Before we turn to our own research, we would like to emphasize that there are other examples of educational studies that used SSG analysis. Vauras et al. (2013) conceptualized teacher–student interaction in terms of scaffolding (Van de Pol, Volman, & Beishuizen, 2010), that is, from a cognitive perspective. Their question was whether and how teachers offer opportunities to learn in class, and how (e.g., whether or not) students respond to these opportunities (i.e., student up-take). Turner et al. (2014) chose yet another way to employ SSGs. First, they combined observations of teacher motivational support with student engagement in a single

grid, that is, they combined “cause and effect” in one trajectory. They crafted grids that summarized interactions in three activity settings as the unit of analysis across 12 lessons per year (for 3 years), instead of micro-level second-to-second interactions. All these studies underpin the versatility of SSG analysis.

Illustration 1: Favorable Interaction States

The goal of this study (Mainhard et al., 2012) was to explore the value of SSG for research on the quality of the classroom social climate by comparing classroom interaction in a classroom of a teacher characterized as drudging (Teacher A), that is with according to students a considerably lower agency and communion, with a class characterized by high levels of both teacher agency and communion (i.e., a positive climate conducive to learning; Teacher B). A cluster of cells was defined as reflecting favorable states of classroom interaction to facilitate the comparison of the two classrooms (see bordered cells in Figs. 12.3 and 12.4). These interpersonally favourable states reflect what Woolfolk Hoy and Weinstein (2006) refer to as a *warm demander*.

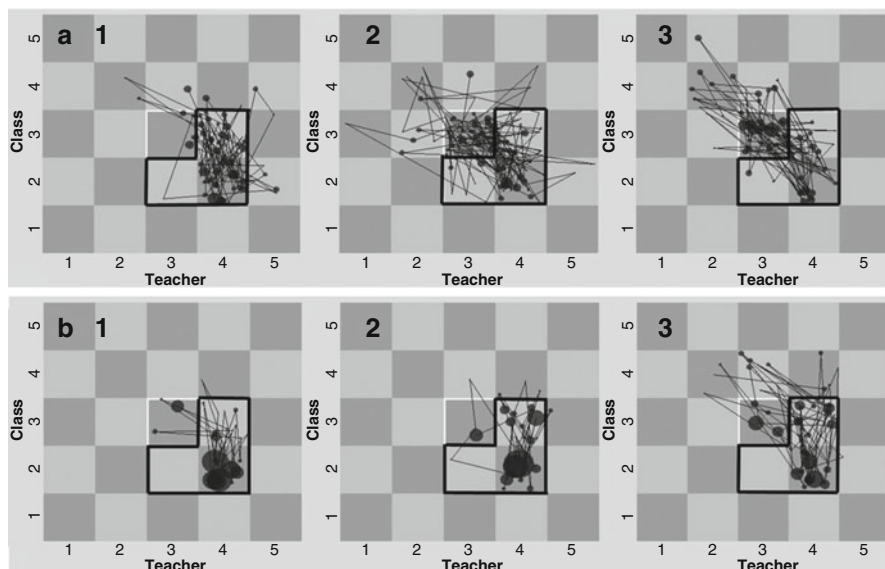


Fig. 12.3 Agency State Space Grids for the two classrooms per lesson. *Bordered cells* represent the favorable interaction area. The *upper panel (a)* refers to the classroom of the drudging teacher, the *lower panel (b)* refers to the classroom with the more positive climate

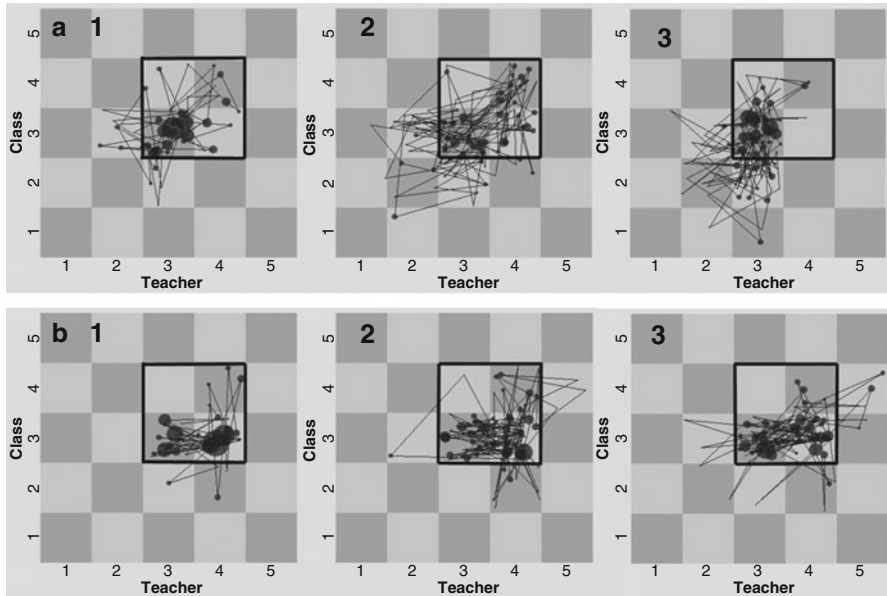


Fig. 12.4 Communion State Space Grids for the two classrooms per lesson. *Bordered cells* represent the favorable interaction area. The *upper panel (a)* refers to the classroom of the drudging teacher, the *lower panel (b)* refers to the classroom with the more positive climate

Approach

Three consecutive lessons in two different classrooms taught by two different teachers were videotaped and coded for teacher agency and communion and class agency and communion. In this study the two interpersonal dimensions were directly coded on a scale running from 1 to 5 (i.e., 1 = very low vs. 5 = very high interpersonal agency). Following an online coding procedure every time either the teacher's or the class's behavior changed a new code was added. Teacher and class were coded separately and subsequently codes were combined into SSG trajectories.

Trajectories and Grid Measures

In this study we chose to craft two 5×5 SSGs which represented the interpersonal teacher–classroom state space: one representing the interactional trajectory in terms of agency (i.e., combining teacher and class agency in one SSG) (Fig. 12.3) and one representing a communion trajectory (Fig. 12.4).

As working hypothesis and in order to compare the two classrooms we defined a *favorable interaction area* reflecting interactional states that we thought of being relatively more positive or constructive than other states. This area of interest was defined based on findings of previous research described by Wubbels et al. (2006).

We used the *perseverance* and *return latency* measures to further explore the areas of interest for these two classrooms' interactional trajectories. To study variability the whole-grid measures *TCT* and *dispersion* were calculated. As higher values of agency and communion are more conducive to learning, the areas we defined here encompass states including relatively high teacher and low student values on agency (i.e., cells 32, 42, and 43), and “neutral” to friendly teacher and student values for communion (i.e., cells 33, 34, 43, and 44). The more favorable areas in the SSG are represented by the bordered cells in the grids (Figs. 12.3 and 12.4). States that include the highest teacher values on agency in combination with the lowest possible student values (e.g., cells 41 or 51, a combination of obedient students and a very strict teacher) were considered as less desirable. Likewise, combinations with very high teacher and student Affiliation values (e.g., cells 54 or 55, the teacher is or tries to be “one of the crowd”) were also regarded as less desirable. Note however, that occasional projections of a trajectory into less favorable areas were not deemed unwanted. On the contrary, occasional interaction in the less favorable areas might sometimes be necessary or beneficial, for example, when a teacher is restricting incidental deviant student behavior.

Findings and Conclusion

Already a first visual inspection of the interactional trajectories shows that the two classrooms differ. Interaction remained longer in a specific state (see the larger dots in the lower panel of Fig. 12.4) in classroom B with the more favorable overall climate, whereas interaction in the upper panel, representing the classroom of the drudging teacher, consists of smaller dots (short durations in a specific state) and more projections in various areas of the grid. Nonetheless, it seemed that the interaction trajectories in both classrooms were rooted within roughly comparable, central regions of the grid. Figures 12.5 and 12.6 summarize the *perseverance* and *return latency* measures for the favorable areas of the agency and communion SSGs as histograms.

For agency, cell 42 had the largest *perseverance* in both classrooms (somewhat higher teacher than student agency) as is indicated by the relatively large *perseverance* bars in Fig. 12.5.

Since a strong *perseverance* may be regarded as an indicator of an *attractor* in a system cell 42 could be regarded as an attractor for both teachers. Yet the interaction of classroom B was more strongly attracted to this specific agency state than classroom A, taking the three lessons together, *perseverance* of cell 42 was twice as large in classroom B ($A = 0.35$; $B = 0.65$). Furthermore, the *return latencies* of the cells included in the favorable agency area indicated that the interaction of classroom B was much faster to return to these favorable states than classroom A. Taking the three lessons together, the shortest *return latency* in classroom A (0.11, cell 43) was about four times longer than the shortest *return latency* of classroom B (0.03, cell 43). Thus the attraction to cell 43 was much stronger for classroom B than for classroom A.

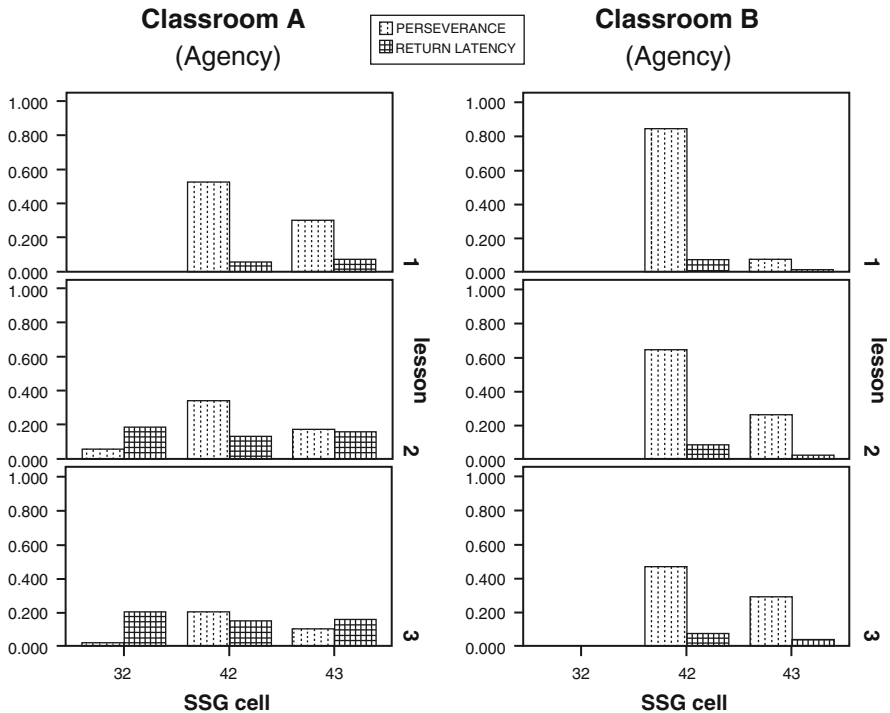


Fig. 12.5 Histograms of perseverance and return latency for agency

The state occurring most frequently in the interaction trajectories for communion of both classrooms was reciprocated “neutral” interaction (cell 33; Fig. 12.4). For example, the teacher goes through a homework assignment without much enthusiasm while students cooperate, but do not contribute spontaneously. Interestingly, in classroom A with the less desirable climate this state had the highest perseverance of all states in this study (0.63, Fig. 12.6). Also, *return latencies* of the states included in the favorable areas were markedly longer for the communion interaction trajectories of classroom A (see Fig. 12.6). In the more positive classroom B however, from lesson two on a state including warm teacher behavior showed the highest *perseverance* (cell 43, perseverance = 0.56). Thus, interaction in the more positive classroom was more strongly attracted to states including warmer interaction.

In Table 12.1, the whole-grid measures *TCT* and *dispersion* are summarized. Both the agency and communion interaction trajectories of classroom A with the less positive classroom climate were more dispersed and fluctuating than those interaction trajectories of classroom B.

The higher variability of the interaction in classroom A was most obvious in terms of the transitions between interpersonal states (i.e., *TCT*), especially for agency. Overall, it appeared that interaction in classroom B was more consistent and visited more positive interpersonal states.

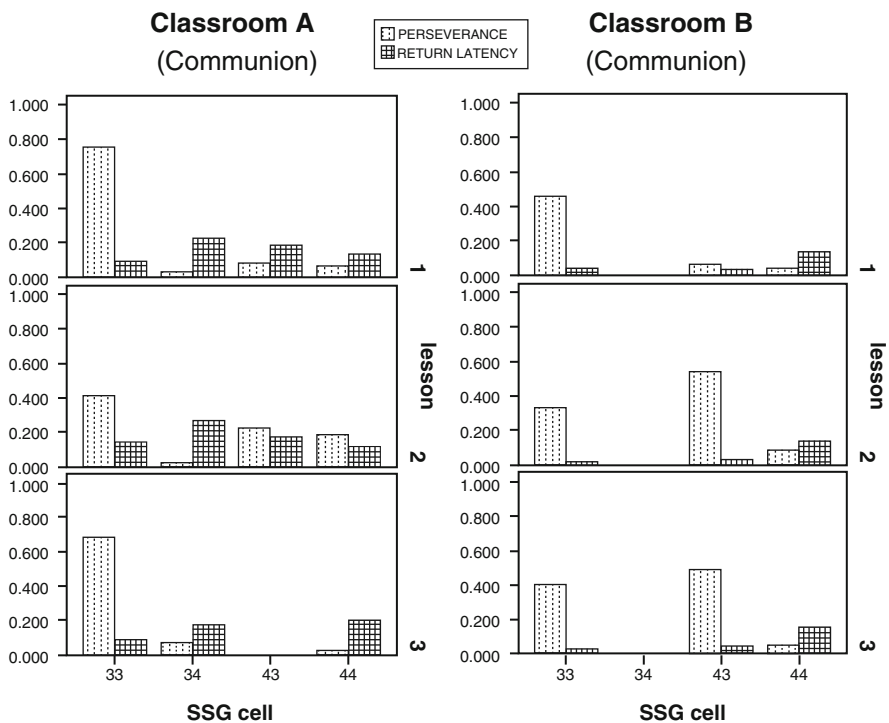


Fig. 12.6 Histograms of perseverance and return latency for communion

Table 12.1 Grid-measures for agency and communion trajectories of the three lessons

	Agency		Communion	
	Total cell transitions	<i>N</i> of visited cells (dispersion)	Total cell transitions	<i>N</i> of visited cells (dispersion)
Classroom A				
Lesson 1	1.62	10	0.97	6
Lesson 2	3.04	10	2.72	11
Lesson 3	1.88	8	1.77	10
Total	2.12	13	1.77	12
Classroom B				
Lesson 1	0.49	4	0.72	5
Lesson 2	0.63	7	1.75	7
Lesson 3	1.11	7	1.44	9
Total	0.74	9	1.30	10

Thus, although interaction in both classrooms was primarily characterized by a positive interpersonal valence, greater variation seemed to be linked to movements away from more favorable interpersonal states, and lower variability seemed to indicate more balanced interpersonal interaction and less “need” for projections into less favorable states.

Classroom A resided relatively longer in less favorable agency and communion states (43 % and 15 % of the total time respectively), while the trajectory of classroom B seemed to just shortly tap these less favorable states (13 % and 4 % of the time), returning quickly to more favorable states, which is also indicated by the smaller and less frequent dots in the B-grids outside the favorable areas (see Figs. 12.3 and 12.4).

An example of a projection into less favorable interaction areas in classroom B is a situation where the teacher was confused about his notes and tried to figure out what he wanted to do; meanwhile the students started to chat rather loudly. However, as soon the teacher had reorganized, the students were back on track immediately. Notably, the agency trajectory of classroom A projected into interpersonal states including the highest teacher values for teacher agency (i.e., cells 52, 53, and 54), which the trajectory in classroom B never did. In classroom A the teacher for example restricted students with a high intensity for relatively minor disruptions, to which the students occasionally responded indignantly.

In classroom A projections of the communion trajectories covered states representing both relatively high-, and low-reciprocated communion (e.g., cells 44 and 22, see Fig. 12.4). In contrast to classroom B, states with the highest teacher communion scores were not covered by the trajectory of classroom A at all.

To sum up, in both classrooms only one clear attractor was found, rather than multiple stable states of interaction. This might reflect the commonly assumed social hierarchy in the classroom, with legitimate teacher power in combination with a basically non-oppositional attitude of both teacher and students towards each other. However, although in both classrooms the same agency attractor existed, it was stronger in the classroom with the more positive social climate. Thus, the differences between the two classrooms were especially apparent in the strength of the attractor and not in its position in the state space. The findings suggest further that variability in interaction is a potent variable in explaining differences in the quality of classroom social climates. In the more negative classroom not only four times more time was spent in less favorable interpersonal states, interaction also shifted far more often between different states (Table 12.1).

Illustration 2: Intrapersonal SSG of Teacher Behavior

In another study (Pennings, Brekelmans et al., 2014) we used a different application of SSGs. We did not study the content and structure of dyadic interactions but instead used SSGs to build intrapersonal trajectories depicting how teacher behavior differs for teachers with different general types of classroom climates.

Approach

To observe sequences of real-time or micro-level teacher behavior we used Sadler's Computer Joystick method (Box 12.1; Sadler, Ethier, Gunn, Duong, & Woody, 2009). This method enabled us to observe teacher behavior (1) as a blend of agency and communion and (2) continuously over time (behavior is coded every half second).

As in Illustration 1, we defined the macro-level *classroom social climate* as aggregated student perceptions of interpersonal teacher behavior, tapped with the Questionnaire on Teacher Interaction (QTI), also in terms of agency and communion. These aggregated perceptions represent relatively stable and predictable patterns of teacher behavior resulting from frequent interpersonal behavior exchanges between a teacher and his or her students (cf., Mainhard et al., 2011).

Assuming that the quality of the classroom social climate is based on student perceptions of actual interactions in class, our goal was to study the correspondence between the location of attractors in teacher behavior and the degree of agency and communion characterizing the general quality of the social climate. Thus, we expected that differences in general climate would be reflected in differences in the content of teachers' micro-level interpersonal behavior as indicated by (a) differences in the strength or existence of attractors and/or by (b) the location of attractors in the SSG. We formulated specific criteria to assess the correspondence between micro-level behavior (i.e., location of attractors) and macro-level classroom social climate. First, we expected that teachers with a classroom social climate characterized by high levels of agency and communion (teacher A and B; Fig. 12.7) would have attractors in the upper right part of the SSG: e.g., frequent occurrences of laughing, helping, and explaining in a friendly manner. Second, we expected that teachers with a classroom social climate characterized by low levels of agency and high levels of communion (teacher C and D) would have attractors in the lower right part of the SSG: frequent occurrences of for example tolerant or understanding behavior. Third, we expected that teachers with a classroom social climate characterized by low levels of agency and communion (teacher E and F) would have attractors in the lower left part of the SSG we used in this study: frequent occurrences of aggressive, hesitating, and uncertain behavior. Finally, we expected teachers with a classroom social climate characterized by high levels of agency and low levels of communion (Teacher G and H) to have attractors in the upper left part of the SSG, reflecting frequent occurrences of, for example, sarcasm or confrontational and enforcing teacher behavior.

Our expectations concerning structure were based on previous findings about which social climate types are most productive in terms of student or teacher outcomes and classroom atmosphere (see for an elaborate overview Wubbels et al., 2006) and also findings from our previous SSG case studies (Mainhard et al., 2012; Pennings, Van Tartwijk et al., 2014). We expected that teachers with climates characterized by lower levels of agency and communion would have higher variability (more visited cells, lower mean durations of visits) and less predictable trajectories (higher entropy) in real-time interpersonal teacher behavior

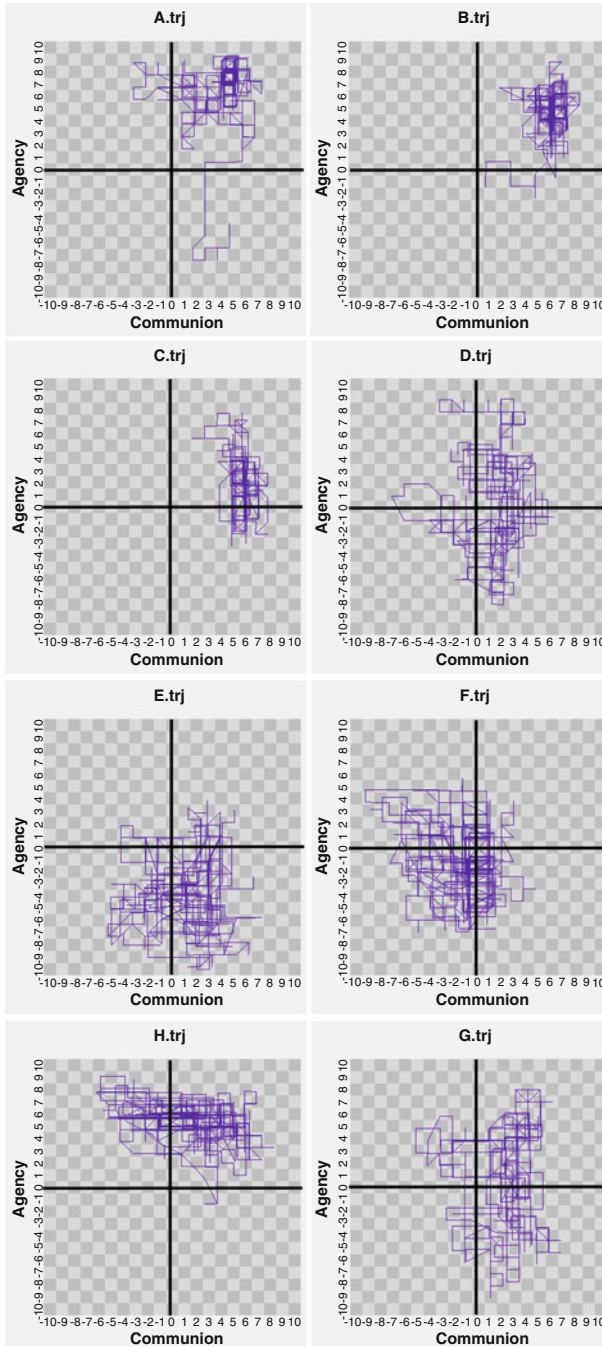


Fig. 12.7 SSGs for eight teacher's (A–H) interpersonal behavior. Agency is represented on the y-axis and Communion on the x-axis. The *black lines* are included to illustrate how the SSGs represent the IPC as an interpersonal grid

than teachers with climates characterized by higher levels of agency and communion. More specifically we expected a negative association between agency and communion with the number of visited cells and with visit entropy, and a positive association between agency and communion and the mean duration per cell visit.

Trajectories and Grid Measures

To analyze the content and structure of micro-level interpersonal teacher behavior, a combined agency and communion SSG was built with Gridware (Lamey et al., 2004). The with the Joystick coded behavior was represented with 20 categories and 1 category included just the 0 value, resulting in 21 categories per dimension ranging from $-10 = \textit{Very low Agency/Communion}$ ($0 = \textit{Neutral}$) to $10 = \textit{Very high Agency/Communion}$. In this study we used what Hollenstein (2013) refers to as the more simple criteria for the identification of attractors. We selected a cell or cluster of cells if (a) the *average duration per cell* was longer than 100 s (i.e., based on 30 min coding and 441 cells) and (b) the *number of visits per cell* was larger than two times the *average number of visits* of all eight teachers.

This study used three whole grid measures concerning the structure of teacher behavior: the *number of unique cells visited*, the *average duration per cell*, and *visit entropy*.

We defined our criterion for differences in structure in real-time interpersonal behavior between teachers as larger than 1 SD difference regarding number of visited cells and mean duration per visit. For visit entropy, we followed the procedure used by Dishion et al. (2004) using boxplots to identify teachers with highly predictable versus highly unpredictable behaviors. Visit entropy values within the first quartile (i.e., 25th percentile) were regarded as low, thus highly predictable. Visit entropy values in the second quartile (i.e., the median split) were regarded as average predictability, and visit entropy values in the third quartile (i.e., 75th percentiles) were regarded as highly unpredictable.

For structure in real-time interpersonal behavior, we explored whether differences between teachers were related to the level of agency and communion of their macro-level classroom social climate. In order to do so we calculated Spearman's rank-order correlations between the grid measures and the continuous scores for agency and communion characterizing the macro-level classroom social climate.

Findings and Conclusion

The SSGs representing the interpersonal behavior of the eight teachers are presented in Fig. 12.7. It can be seen that the trajectories depicted are somewhat different from the example in Fig. 12.2 and the SSGs in Illustration 1. GridWare provides two options for visualization, the random and the diagonal layout of SSGs. The SSGs in Figs. 12.2, 12.3, and 12.4 are examples of the random layout, but for the SSGs in Fig. 12.7 (and also Fig. 12.8) we used the diagonal layout. Also, the

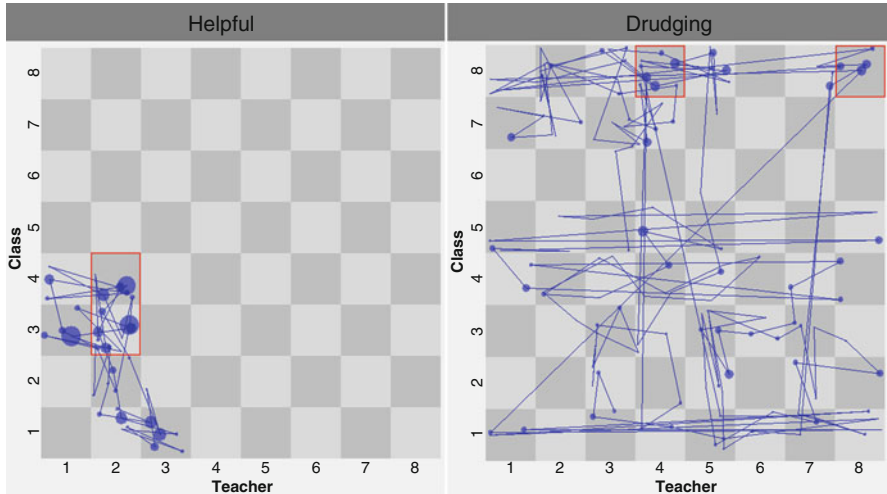


Fig. 12.8 SSG for a helpful and a drudging teacher in this study. The number 1–8 correspond to the octants of the IPC-T/IPC-S 1 is the *upper right* octant (i.e., assured/pro-active) and 8 is the *upper left* octant (i.e., imposing/critical). The red lines mark the identified attractor cells

nodes are not really visible in these SSGs, the reason for this apparent lack of nodes is that the interaction trajectory is 30 min long and the number of possible cells is very high, transitions to adjacent cells occur more frequently and as a result the nodes are very small and almost invisible.

Visual inspection of the different SSGs in Fig. 12.7 already shows some obvious differences between the selected teachers in terms of their real-time behavior trajectories. The trajectory of Teacher B for example was characterized by almost entirely highly communal and agentic interpersonal states. Compared to Teacher E’s behavior, who seemed very submissive and frequently switching between unfriendly and friendly behavior, the behavior of Teacher B seemed much more predictable. The grid measures as presented in Table 12.2 confirmed this (i.e., 43 versus 112 visited cells, an average of 42.57 versus 16.26 s visit duration, and the lowest versus one of the highest values for visit entropy).

The identified attractor cell(s) with corresponding values for *perseverance* and number of visits are presented on the right in Table 12.2. The level of agency in teacher behavior corresponds to the *y*-part and the level of communion in teacher behavior corresponds to the *x*-part of the cell(s).

Figure 12.7 and Table 12.2 indicate that the majority of the attractors in teacher behavior trajectories were found in the SSG area corresponding to the levels of general agency and communion that characterized the macro-level social climate of that teacher. Note that for teachers D, E, and G, no specific attractors could be identified.

Most results for structure were in line with our hypothesis, yet for teacher A, D and H the findings were only partly in line with the hypotheses. For example, we

Table 12.2 Results for content and structure in interpersonal teacher behavior

	Whole grid measures			Attractor cells		
	Number of visited cells	Average cell duration	Visit entropy	Cells	Perseverance	Number of visits
A	75	24.98	3.54	48	107.0	41
				74	166.5	48
				95	110.5	18
				58	209.0	43
				57	166.5	55
B	43	42.57	3.07	55	143.50	28
				66	172.5	46
				65	199.5	56
				64	212.5	62
C	44	41.56	3.29	5–1	101.0	15
				63	115.5	34
				62	124.5	35
				6–1	360.5	20
D	103	17.51	4.35	NAS	–	–
E	112	16.26	4.39	NAS	–	–
F	114	15.82	4.23	–1–2	108.5	41
G	113	15.62	4.46	NAS	–	–
H	88	20.34	3.99	46	102.0	26

Note. NAS no attractor specified

expected that the number of visited cells would be lower for teacher A and higher for teacher H, both numbers of visited cells were indeed lower than the number of visited cells for teacher D, E, F, and G. Yet based on the desirableness of the classroom social climates we expected that the number of visited cells for teacher A would be more similar to teacher B, and for teacher H we expected that the number of visited cells would be more similar to teacher C. The result showed that teacher A and H were more similar and teacher B and C were more similar in the number of visited cells.

We calculated Spearman's rank correlations to explore whether differences between teachers were related to the level of agency and communion characterizing the teachers' macro-level social climate. For *Number of visits* and *Visit entropy*, we found negative correlations with agency. Respectively Spearman's Rho were -0.36 and -0.05 . For *Duration in visited cells* we found a positive correlation, Spearman's Rho was 0.33 . However, none of the correlations were significant.

For communion we also found very high and significant correlations with all three whole grid measures. For *Number of visits* and *Visit entropy*, we found negative correlations with communion. Respectively Spearman's Rho were -0.90 and -0.73 , and for *duration in visited cells* we found a positive correlation, Spearman's Rho was 0.86 . Thus, we could only confirm our hypothesis about the relation between macro-level communion and micro-level structure of interpersonal teacher behavior.

Overall, using SSGs in this study allowed us to visualize and study how the content and structure of interpersonal teacher behavior and to show how they differentiate between teachers with different types of classroom social climates.

Illustration 3: Interpersonal SSG of Teacher–Class Interaction

In a recent study (Pennings et al., 2015) we studied the content, structure, and degree of complementarity in teacher–student interactions during the lesson start of 35 teachers with different classroom social climates. In order to do so we included observations of both the teacher’s and the students’ (coded as whole class) behavior.

Approach

Our observational approach was similar to our approach in Illustration 2. Again we used the joystick method (Box 12.1) to observe interpersonal teacher behavior, yet for this study we also included observations of class interpersonal behavior. Since we included 35 teacher–class dyads we were able to use some additional statistical analyses to study differences between teachers.

Also, we introduce a new concept in this study, the concept of *complementarity* which is rooted in interpersonal theory. The principle of complementarity defines how the interpersonal behaviors of both participants fit together, mutually adjust to each other, and how this dynamically changes during interactions. Complementarity in terms of agency is called *reciprocity*, and denotes the tendency to pull an interaction partner towards *oppositeness*. Complementarity in terms of communion is called *correspondence*, and denotes the tendency to pull a partner in interaction towards *sameness* (Sadler et al., 2009).

Trajectories and Grid Measures

The SSGs in this illustration represent dyadic behavior states (combinations of teacher and class behavior) and are therefore comparable to the SSGs presented in Illustration 1. The difference is that in the present illustration we combined the level of agency and communion in teacher and class behavior into one SSG. In order to do so we recoded (following a procedure described by Gurtman, 2011) the joystick data into eight categories corresponding to the octants of the IPC-T and IPC-S and collapsed those on the *x*-axis (teacher) and *y*-axis (class) of the SSG. This yielded SSGs similar to the example SSG provided in Fig. 12.2.

In this study we used the winnowing procedure (Hollenstein, 2013; Lewis et al., 1999) to empirically derive attractors to study the content of the interactions. We expected that the octant representing the teacher behavior component of the attractor cell(s) (micro-level data) would correspond to the octant that characterized the

classroom social climate (macro-level data). Given the complementarity principle we expected that octants corresponding to the class behavior component of the attractor cell(s) would represent opposite behavior for teacher agency and similar behavior for teacher communion. Thus, if the attractor cell corresponds to the first octant for teacher behavior (assured; i.e., which is characterized by high levels of agency and moderately high levels of communion), we expected that the octant for class behavior would be octant 4 (reliant; i.e., which is characterized by low levels of agency and moderately high levels of communion).

For structure we formulated the following expectations based on our previous studies; we expected that interactions of teachers with desirable classroom social climates would be less variable than interactions of teachers with less desirable classroom social climates. To study the structure of the teacher–class interactions we used the *grid range*, the *duration per cell*, the *number of transitions*, *duration per visit*, *dispersion*, and *visit entropy*.

Findings and Conclusion

The SSGs for the teacher–class interaction of two of the 35 teachers are presented in Fig. 12.8. One for a assured teacher and one for a drudging teacher. These two SSGs show differences between the interactions trajectories of both teachers.

In Table 12.3 the results of the winnowing procedure are provided. For most teachers one or two attractor cells are identified. The perseverance values show that for those teachers the attractors are strong. For some teachers more than two attractors are identified, for these teachers the attractors are weaker. Also for both the helpful (16) and drudging teacher (27), of whom the SSGs are provided in Fig. 12.8, two attractor cells are identified. However, the location and strength of these attractors is quite different. For the helpful teacher the attractor shows that the teacher mainly shows helpful behavior and the students mainly are reliant or collaborative (i.e., cell 24 and 23). The two cells are adjacent to each other and together form an attractor region. For the drudging teacher two quite different cells are identified as attractors, the drudging teacher shows imposing and compliant behavior and the students mainly show critical behavior (i.e., cell 48 and 88). That the strength of the drudging teacher’s attractors is weaker than those of the helpful teacher, which can also be seen in the visualizations of the SSG as well as in the grid measures that represent structure, provided in the next section (Table 12.3).

From Table 12.3 it can also be seen that 32 out of 35 teachers have at least one attractor where teacher behavior is characterized by assured or helpful behavior. Of these 32 teachers 10 teachers have attractors with students also showing more agentic (i.e., critical, proactive or supportive) behavior. Most of these teachers have a drudging classroom social climate according to their students. The other three teachers have attractors of compliant or imposing behavior, it can also be seen that students of these teachers are mainly critical, confrontational or dissatisfied. These three teachers all have drudging classroom social climates.

Table 12.3 Attractor cells (and regions) with corresponding total duration (perseverance)

Teacher ID	Attractor 1 (perseverance)	Attractor 2 (perseverance)	Attractor 3 (perseverance)	Attractor 4 (perseverance)	Attractor 5 (perseverance)	Attractor regions (perseverance)
1	34 (140.50)	24 (137.50)	48 (86.50)	-	-	34/24 (278.00)
2	24 (128.50)	23 (100.00)	-	-	-	24/23 (228.50)
3	36 (124.00)	37 (91.00)	-	-	-	36/37 (215.00)
4	14 (79.00)	37 (59.00)	17 (54.50)	-	-	
5	13 (107.00)	32 (101.50)	-	-	-	
6	14 (164.50)	38 (116.00)	-	-	-	
7	22 (179.50)	32 (166.50)	-	-	-	22/32 (346.00)
8	13 (212.50)	12 (194.50)	28 (99.00)	-	-	13/12 (407.00)
9	24 (260.50)	14 (138.50)	-	-	-	24/14 (399.00)
10	24 (235.50)	-	-	-	-	
11	14 (257.50)	-	-	-	-	
12	14 (142.50)	13 (83.00)	-	-	-	14/13 (225.50)
13	14 (166.50)	11 (107.00)	21 (94.00)	-	-	11/21 (201.00)
14	14 (324.00)	-	-	-	-	
15	22 (318.50)	-	-	-	-	
16	23 (174.00)	24 (130.00)	-	-	-	23/24 (304.00)
17	24 (244.50)	-	-	-	-	
18	23 (298.50)	-	-	-	-	
19	14 (289.00)	-	-	-	-	
20	21 (92.00)	13 (88.50)	-	-	-	
21	14 (235.50)	-	-	-	-	
22	24 (214.50)	-	-	-	-	
23	48 (233.00)	-	-	-	-	
24	14 (141.50)	13 (105.50)	84 (78.00)	-	-	14/13 (247.00)
25	22 (121.50)	21 (105.00)	28 (84.50)	-	-	22/21/28 (311.00)

26	13 (238.00)	14 (232.50)	–	–	–	13/14 (470.50)
27	48 (80.50)	88 (56.50)	–	–	–	–
28	13 (226.00)	23 (132.50)	–	–	–	13/23 (358.50)
29	24 (161.00)	22 (124.00)	–	–	–	–
30	24 (160.00)	21 (126.00)	–	–	–	–
31	22 (117.00)	21 (113.00)	23 (88.50)	28 (69.50)	–	22/21/23/28 (388.00)
32	14 (113.00)	15 (83.50)	–	–	–	14/15 (196.50)
33	14 (301.00)	24 (229.50)	–	–	–	14/24 (530.50)
34	14 (102.00)	38 (100.00)	24 (99.50)	13 (54.50)	28 (53.00)	14/24/13 (256.00) 38/28 (153.00)
35	14 (343.00)	–	–	–	–	–

Note. Perseverance is the total duration in the attractor cell, provided in seconds. The attractor cells are named by first giving the octant number for the teacher and then for the student. Thus teacher octant 1 and student octant 4 give results in cell number 14

Table 12.4 Means and standard deviations for the grid measures

Style	Grid range	Number of transitions	Dispersion	Visit entropy	Duration per cell	Duration per visit
1	12.50 (3.27)	43.83 (7.73)	0.73 (0.10)	2.16 (0.46)	50.11 (14.48)	13.77 (2.53)
2	12.84 (4.02)	43.23 (14.46)	0.80 (0.08)	2.26 (0.32)	49.80 (14.75)	14.13 (4.07)
3	15.33 (5.51)	61.00 (39.15)	0.78 (0.10)	2.40 (0.30)	42.95 (19.36)	143.80 (12.71)
4	16.50 (0.71)	54.50 (7.78)	0.89 (0.04)	2.59 (0.08)	35.64 (1.53)	10.89 (1.55)
8	18.33 (3.27)	77.00 (30.80)	0.90 (0.01)	2.66 (0.06)	32.19 (2.62)	8.76 (4.29)
9	24.13 (12.56)	76.50 (32.89)	0.87 (0.08)	2.83 (0.52)	30.40 (14.35)	8.94 (3.67)
Total	16.26 (7.98)	56.74 (25.75)	0.82 (0.09)	2.44 (0.44)	42.51 (15.80)	12.30 (5.13)

Note. Standard deviations are presented within brackets

In Table 12.4 the overall means and standard deviations of the grid measures of the 35 teachers and the means and standard deviations per classroom social climate are provided. We concluded that there are large variations between the teachers for most grid measures.

In this study we carried out quantitative statistical analyses to study differences in teachers' grid measures. Six separate ANOVAs were carried out to compare grid measures between teachers with different classroom social climates. The results showed that all grid measures except *duration per visit* [$F(5, 29) = 1.75, p = 0.156$] showed significant differences between teachers with different classroom social climates. Post hoc tests showed that: (1) For *Grid range* [$F(5, 29) = 3.06, p = 0.025$] teachers with a drudging classroom social climate visited significantly more cells than teachers with assured ($p < 0.01$) and helpful ($p < 0.01$) classroom social climates. (2) The *Number of transitions* [$F(5, 29) = 2.69, p = 0.041$] was significantly higher for teachers with an imposing classroom social climate compared to teacher with a helpful classroom social climate ($p < 0.05$). Teachers with a drudging classroom climate switched cells significantly more often than teachers with an assured ($p < 0.05$) or helpful ($p < 0.01$) climate. (3) For *dispersion* [$F(5, 29) = 2.99, p = 0.027$] teachers with an assured classroom social climate had significantly lower dispersion than teachers with a compliant ($p < 0.05$), imposing, or drudging ($p < 0.01$) climate. (4) For *Visit Entropy* [$F(5, 29) = 3.03, p = 0.024$] teachers with a drudging climate had significantly higher visit entropy values than teachers with an assured or helpful classroom social climate ($p < 0.01$). (5) For *Duration per cell* [$F(5, 29) = 2.60, p = 0.047$] teachers with a drudging social climate had significantly lower cell durations than teachers with an assured ($p < 0.05$) or helpful ($p < 0.01$) climate. Thus, these results showed that especially teachers with a drudging social climate, which is relatively less desirable, show significantly more variability in their interactions with the class than teachers with assured and helpful social climates, which are the most desirable social climates in terms of student and teacher outcomes.

In sum, the study showed that the number, the strength, and the location of attractors varies between teachers with different classroom climates. Also, a quantitative comparison of the interaction trajectories in terms of the grid measures showed, for example, that teachers with less desirable classroom climates changed their behavior more often and were relatively more unpredictable.

Illustration 4: Interpersonal Teacher Behavior and Student Behavioral Engagement

This example was adapted from an unpublished study (Pennings et al., 2012). In this study we observed in four teacher–class dyads interpersonal teacher behavior and student behavioral engagement (Fredricks, Blumenfeld, & Paris, 2004) in terms of active or passive on- and off-task behavior (Skinner, Kindermann, & Furrer, 2009). The idea of this study was that students of teachers with classroom social climates characterized by higher levels of agency and communion have better academic results (Wubbels et al., 2006) and show more behavioral engagement (Birch & Ladd, 1997; Valeski and Stipek (2001).

Skinner and Belmont (1993) for example, found that students' emotional and behavioral engagement was not only influenced by their perception of the classroom social climate, but also by the teachers actual behavior. Therefore we wanted to observe interpersonal teacher behavior in connection with student behavioral engagement. In this illustration we stick to what can be seen in the SSGs. We included this example for the purpose of illustrating that it is also possible (1) to create SSGs with different kinds of behavior for the two parties in the interaction (i.e., interpersonal behavior vs. student behavioral engagement), and (2) to create asymmetrical SSGs (i.e., 8×4 SSGs).

Approach

Participants were four secondary school teachers with their students. These teachers were chosen based on their classroom social climate (based on their agency and communion scores measured with the QTI). Figure 12.9 the SSGs of the four teachers are ordered following the quality of the social climates of these teachers (i.e., teacher A in the upper right quadrant; teacher B in the lower right quadrant; teacher C in the lower left quadrant; and teacher D in the upper left quadrant of the IPC-T).

We used the joystick method (Box 12.1) to observe teacher behavior the same way we described in Illustration 2 and 3. Yet we also used the joystick method to observe student/class engagements as two dimensions. The horizontal axis was used to observe on-task (+) vs. off-task (–) student behavior, and the vertical axis was used to code whether on/off-task behavior was active (+) or passive (–).

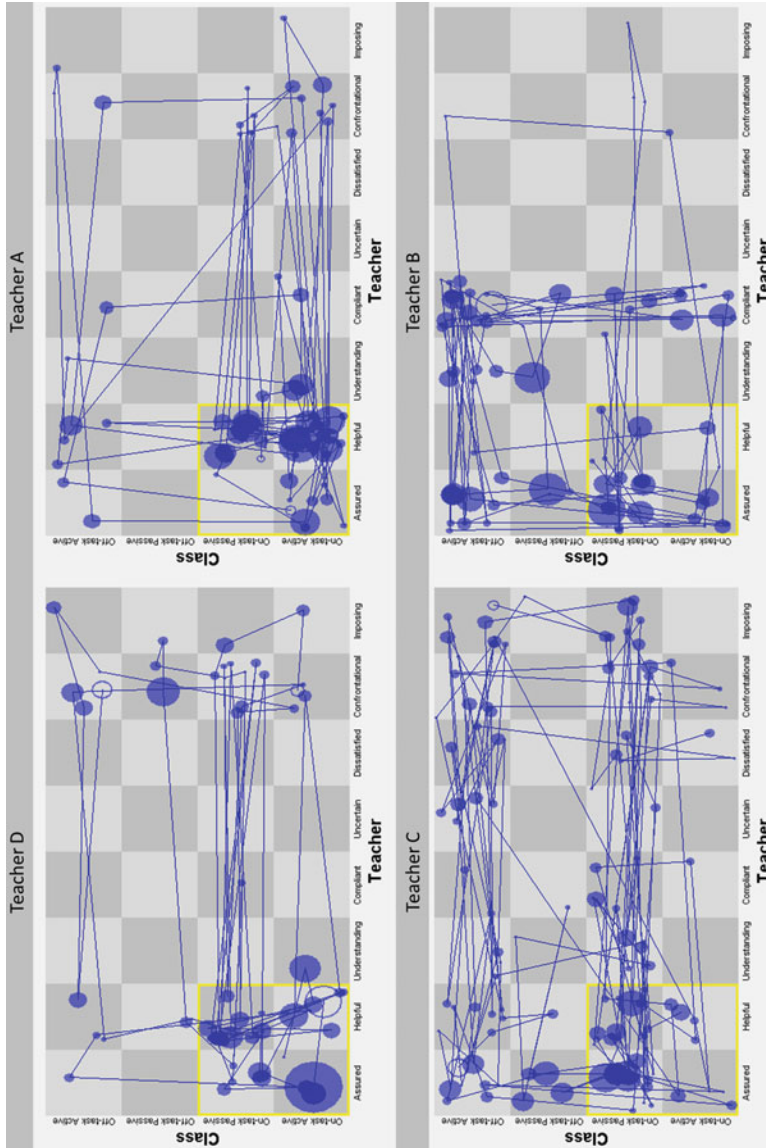


Fig. 12.9 SSGs for teacher–class A–D showing teacher interpersonal behavior on the x-axis and class behavioral engagement on the y-axis

Gurtman’s (2011) procedure was used to recode teacher interpersonal behavior coordinates into the octants of the IPC-T. The student engagement coordinates were also recoded following this procedure, but an additional computation was used to combine the octants into quadrants, resulting into four categories representing the observation categories defined by Skinner et al. (2009): (1) On-task active (upper right quadrant), (2) On-task Passive (lower left quadrant), (3) Off-task Passive (lower left quadrant), and (4) Off-task Active (upper left quadrant).

Findings and Conclusion

As can be seen in Fig. 12.9, the four lower left cells (11, 12, 21, and 22) in the SSGs are marked with a thicker line.

This area is the predefined area of interest where teacher behavior is assured and helpful and student behavior is active or passive on-task. All four interactions regularly visit the cells in this area. The nodes in this area of interest are larger for teacher A and D, than for teacher B and C. This means that the duration of individual visits to these states for teacher A and D were longer than for teacher B and C. The SSGs also show that the interactions of teacher A and D less often and for shorter durations of time visited areas of the grid where students are off-task than teacher B and C. In addition, the interactions of teacher C and D show more behavior that is characterized by lower levels of communion (i.e., uncertain, dissatisfied, confrontational or imposing behavior) than teacher A and B.

Thus, even without using any grid measures the visual information provided by the SSGs provides information about the interactions in these classrooms. It also shows that although classroom social climates (macro-level) of these four teachers are different with some being more favorable, that students in all classrooms still show some degree of on-task behavior, and that teachers show some degree of assured and helpful behavior.

Box 12.1: Sadler’s Computer Joystick Method for Observation of Interpersonal Teacher and Student Behavior

Interpersonal behavior of students and teachers was coded continuously within the IPC following an online-scoring procedure and using Sadler’s joystick tracking method (Fig. 12.10) (Sadler et al., 2009).

(continued)

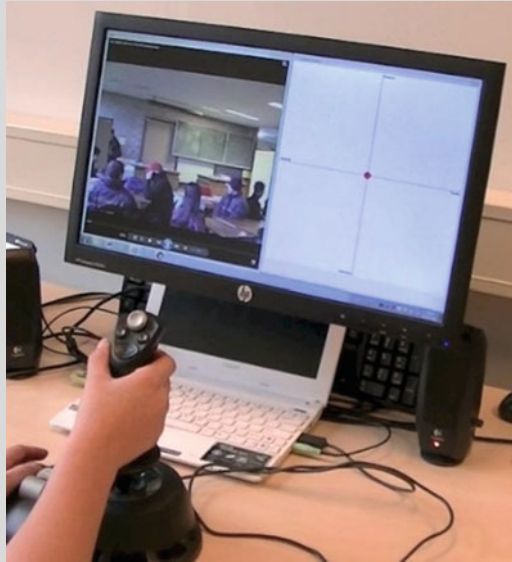
Box 12.1 (continued)

Fig. 12.10 Sadler's computer Joystick observation (this picture is adapted from Pennings, Brekelmans et al., 2014)

First teacher behavior and then student behavior was coded in separate observation sessions. The joystick tracking device is designed to observe verbal and nonverbal behaviors that have clear interpersonal meaning (Markey, Lowmaster, & Eichler, 2010). By moving the joystick in a certain direction the behavior of people can be observed (a) continuously in time (online observation) and (b) represented as a degree of both agency and communion (Markey et al., 2010). Thus, an observer moves the joystick to code the teacher's or the students' ongoing interpersonal behavior, while watching a video recording of a lesson. The joystick device enabled us to observe behavior as a specific blend of agency and Communion, instead of coding behavior separately (and arbitrarily) for both dimensions.

Joymon

This joystick method comes with a computer program (Joymon.exe; Lizdek, Sadler, Woody, Ethier, & Malet, 2012) that numerically records the exact location (based on X- and Y-coordinates) of the joystick within a two dimensional space, meant to represent the IPC (Markey et al., 2010; Sadler et al., 2009). During the observation, a dot in the IPC (i.e., presented in a separate

(continued)

Box 12.1 (continued)

screen) marks the exact location of the joystick. These behavior coordinates ranged from -1000 (i.e., very low agency/Communion) to $+1000$ (very high agency/Communion). This range is a default setting of the *joymon-progam* and ensures maximum sensitivity of the computer joystick device. Also, by default the program is set to record the joystick cursor's location twice per second. We also used this default setting to record teacher and student behavior twice per second.

Thus, in a study where 10 minute interactions are observed, about 600 behavior coordinates were provided for agency and Communion, per teacher and class. For a more elaborate description of this computer joystick procedure see Lizdek et al. (2012).

Joystick Training and Interrater Reliability

To learn how to observe teacher–student interactions with the computer joystick two of the researchers (first author and last author of the study presented in illustration 3) participated in a computer joystick training provided by Pamela Sadler. Four trained observers independently coded the videos. Every video was coded by two out of these four observers. Interrater reliability was established for the observations by calculating intraclass correlations (ICC(K); Markey et al., 2010; Thomas et al., 2014). Resulting in ICC(K = 2) values of 0.72 for teacher agency, 0.84 for teacher communion, 0.82 for student agency, and 0.89 for student communion. This indicated strong agreement between the observers (LeBreton & Senter, 2008).

General Discussion

Our goal for this chapter was to illustrate a process oriented way of doing classroom research. We wanted to show how moment-to-moment or *real-time* classroom interaction can be captured and studied with State Space Grids (SSGs) (Hollenstein, 2013; Lewis et al., 1999). We think that SSGs are a suitable tool for many issues that arise when classroom or educational processes are approached from a CDS perspective. SSGs make it possible to visualize and capture many features of real-time interaction. This in turn allows us to study how higher levels developmental outcomes, like the quality of the classroom climate or for instance student engagement, are grounded in real-time processes but also how they restrain those real-time processes at the same time. Therefore, SSGs offer a way to move away from solely product oriented research that summarizes entire lessons or even larger time units in single measures. An approach that is much needed in order for educational scientists to make a contribution to educational practice (Koopmans, 2014; Wubbels et al., 2012).

We provided four illustrations of how we approached the study of the classroom social climate and its connection with teacher interpersonal behavior and teacher student interactions. We think that using SSGs has advanced our understanding of teaching in terms of what teachers seem to have in common regarding interpersonal processes, but also in terms of differences between teachers and types of classroom climates.

One basic observation is that visualizations of interactions in different classrooms are already compelling in the way they convey differences and sameness between teachers. In exploratory studies this helps to formulate hypotheses about the content and structure of interactions, which can be tested with more advanced methods and larger sample studies. For example, in all of the illustrations the visual inspection of the SSGs shows that there seems to be a rather common base in the interpersonal state space all teachers share and that in most classrooms only this one general attractor exists. This common base consists of states where teacher and class are both friendly (or on-task for students), for example by showing assured and helpful behavior. Yet variation on the agency dimension in combination with friendliness (high communion) is possible. Note that for classrooms in which this area is not an attractor as such, the interaction still visits this area quite often. Therefore, differences between teachers seem to be rooted more in the way they move in and out of this area or an attractor, rather than in where an attractor is located. Indeed, as the illustrations included in this chapter show, this first observation is confirmed when more sophisticated grid- and cell-measures are employed. Specifically in Illustration 3, which uses relatively more advanced techniques and the largest sample, it becomes clear that there is something like a commonly assumed social hierarchy in the classroom, with legitimate teacher power in combination with a basically non-oppositional attitude of both teacher and students towards each other (moderately high agency and communion or in other words assured or helpful teacher behavior).

Notwithstanding these common features of classrooms, a lot of differences in interaction were detected. The main theme seems to be that the more favorable the general classroom climate (also in terms of student and teacher outcomes; Wubbels et al., 2006), the more firmly interaction is rooted in a moderately high agency and communion attractor, and the more classrooms divert from this more favorable states, the more variable or chaotic classroom interaction becomes. This is apparent in all of the four illustrations used here and specifically reflected in grid- and cell-measures like the number of transitions between states, duration per cell, but also more sophisticated measures like visit entropy. Not only teachers that have a what we have called drudging social climate in class change more often between interpersonal states, also interactions in classrooms of teachers where the classroom social climate is generally imposing or compliant, interactions showed relatively more variability. Indeed, as Illustration 2 shows, correlations between agency and communion and many of the measures that indicate variability are negative, indicating that less social influence and less warmth go together with more variability in classroom interaction.

Not only variability indicated less favorable interactions, interactions may also visit more “extreme” cells of the grid (for example states including the highest

scores for teacher dominance) from time to time (see for example discussion of Illustration 1). As these extreme episodes of interaction seem to be very short, it is questionable whether such a characteristic of classroom interaction could have been captured with more product oriented approaches.

We think that the use of SSG is attractive also because of the intuitive way of visualizing data and the versatile way in which grids can be built and employed. Indeed, there are many ways in which SSGs can be build, varying the combinations of dimensions, methods of observation, study individual behavior (e.g., Pennings, Brekelmans et al., 2014), dyadic interactions (e.g., Granic et al., 2003; Mainhard et al., 2012), and even triadic interactions (e.g., Lavictoire et al., 2012) and one can chose to conceptualize development and visualize trajectories over time (e.g. Granic et al., 2003; Turner et al., 2014). Also the possibilities for the interpretation of the resulting data are virtually infinite. Possibilities for analysis start from mere visual inspection of SSGs, include qualitative comparison of cell and whole grid measures (e.g., Illustration 1), but also allow researchers to conduct more advanced analysis, for example by using the winnowing procedure for attractor identification. Of course it is also possible to use any measure resulting from SSG-analysis in more “classical” statistical analyses (see Illustration 3) and in multilevel or structural equation modeling to test hypotheses. Thus, researchers with various degrees of statistical knowledge should be able to profit from this tool. Bear in mind, however, that the SSG technique is merely as good as the data that is used. It totally depends on the theoretical rigor that underlies the decisions made by the researcher who builds the grids.

Overall, SSGs and CDS thinking are very promising in educational research, because they provide the means to study individual teachers, teacher–student/class dyads, teacher teams, teachers with parents, or student–student interactions. It is possible to generalize results across, for example, teachers but also to focus on individual development of teachers or students. The insights in the differences in content and structure that we have found in our studies can easily be incorporated in professional development courses for teachers (e.g., to create awareness on the effect of behavior in interactions with students on the teacher–student relationship or the general classroom social climate; Pennings, Van Tartwijk et al., 2014). The interested reader should turn to Hollenstein (2013) for a more comprehensive introduction to SSG analysis or should consult the GridWare manual (Lamey et al., 2004).

References

- Bento, T., Ribeiro, A. P., Salgado, J., Mendes, I., & Gonçalves, M. M. (2014). The narrative model of therapeutic change: An exploratory study tracking innovative moments and protonarratives using state space grids. *Journal of Constructivist Psychology*, 27(1), 41–58.
- Birch, S. H. & Ladd, G. W. (1997). The teacher–child relationship and children’s early school adjustment. *Journal of School Psychology*, 35, 61–79.
- Bronfenbrenner, U., & Morris, P. A. (2006). The bioecological model of human development. In W. Damon & R. M. Lerner (Eds.), *Handbook of child psychology, Vol. 1: Theoretical models of human development* (6th ed., pp. 793–828). New York: John Wiley.

- Claessens, L. C. A., Pennings, H. J. M., Van Der Want, A. C., Van Tartwijk, J., Brekelmans, M., & Den Brok, P. (2014). De docent en het sociaal klimaat in de klas: een benadering vanuit interpersoonlijk perspectief [The teacher and the classroom social climate: From an interpersonal perspective]. *Pedagogische Studien*, *91*, 300–315.
- Cornelius-White, J. (2007). Learner-centered teacher-student relationships are effective: A meta-analysis. *Review of Educational Research*, *77*(1), 113–143. doi:10.3102/003465430298563.
- Créton, H. A., Wubbels, T., & Hooymayers, H. P. (1989). Escalated disorderly situations in the classroom and the improvement of these situations. *Teaching and Teacher Education*, *5*(3), 205–215.
- De Jong, R. J., Van Tartwijk, J., Verloop, N., Veldman, I., & Wubbels, T. (2012). Teachers' expectations of teacher-student interaction: Complementary and distinctive expectancy patterns. *Teaching and Teacher Education*, *28*, 948–956. doi:10.1016/j.tate.2012.04.009.
- Dishion, T. J., Nelson, S. E., Winter, C., & Bullock, B. (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*, 651–663. doi:0091-0627/04/1200-0651/0.
- Fournier, M. A., Moskowitz, D. S., & Zuroff, D. C. (2011). Origins and applications of the interpersonal circumplex. In L. M. Horowitz & S. Strack (Eds.), *Handbook of interpersonal psychology* (pp. 37–56). New York: Wiley.
- Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, *74*, 59–109. doi:10.3102/00346543074001059.
- Granic, I., & Hollenstein, T. (2003). Dynamic systems methods for models of developmental psychopathology. *Development and Psychopathology*, *15*(3), 641–669. doi:10.1017/S0954579403000324.
- Granic, I., Hollenstein, T., Dishion, T. J., & Patterson, G. R. (2003). Longitudinal analysis of flexibility and reorganization in early adolescence: A dynamic systems study of family interactions. *Developmental Psychology*, *39*, 606–617.
- Guastello, S. J., Koopmans, M., & Pincus, D. (2009). *Chaos and complexity in psychology: The theory of nonlinear dynamic systems*. New York: Cambridge University Press.
- Guastello, S. J., & Liebovitch, L. S. (2009). Introduction to nonlinear dynamics and complexity. In S. J. Guastello, M. Koopmans, & D. Pincus (Eds.), *Chaos and complexity in psychology: The theory of nonlinear dynamic systems* (pp. 1–40). New York: Cambridge University Press.
- Gurtman, M. B. (2009). Exploring personality with the interpersonal circumplex. *Social Psychology Compass*, *3*, 1–19. doi:10.1111/j.1751-9004.2009.00172.x.
- Gurtman, M. B. (2011). Circular reasoning about circular assessment. In L. M. Horowitz & S. Strack (Eds.), *Handbook of interpersonal psychology* (pp. 209–312). New York: Wiley.
- Henderson, D. G. (1995). *A study of the classroom and laboratory environments and student attitude and achievement in senior secondary biology classes*. Unpublished doctoral dissertation, Curtin University of Technology, Perth.
- Henderson, D. G., & Fisher, D. L. (2008). Interpersonal behaviour and student outcomes in vocational education classes. *Learning Environments Research*, *11*, 19–29. doi:10.1007/s10984-007-9034-z.
- Hollenstein, T. (2007). State space grids: Analyzing dynamics across development. *International Journal of Behavioral Development*, *31*, 384–396. doi:10.1177/0165025407077765.
- Hollenstein, T. (2013). *State space grids: Depicting dynamics across development*. New York: Springer.
- Hollenstein, T., & Lewis, M. D. (2006). A state space analysis of emotion and flexibility in parent-child interactions. *Emotion*, *6*(4), 663–669. doi:10.1037/1528-3542.6.4.656.
- Hong, J., Hwang, M., Tam, K., Lai, Y., & Liu, L. (2012). Effects of cognitive style on digital jigsaw puzzle performance: A GridWare analysis. *Computers in Human Behavior*, *28*, 920–928.
- Horowitz, M. L., & Strack, S. (2011). *Handbook of interpersonal psychology*. New York: Wiley.
- Kiesler, D. J. (1996). *Contemporary interpersonal theory and research*. New York: Wiley.

- Koopmans, M. (2014). Change, self-organization and the search for causality in educational research and practice. *Complicity: An International Journal of Complexity and Education*, 11(1), 20–39. Retrieved from: <http://wigan-ojs.library.ualberta.ca/index.php/complicity/article/view/19523/16145>.
- Lamey, A., Hollenstein, T., Lewis, M. D., & Granic, I. (2004). GridWare (Version 1.1). [Computer software]. <http://statespacegrids.org>
- Lavelli, M., Pantoja, A. P. F., Hsu, H., Messenger, D., & Fogel, A. (2005). Using microgenetic designs to study change processes. In D. M. Teti (Ed.), *Handbook of research methods in developmental science* (pp. 40–65). Malden, MA: Blackwell Publishing.
- Lavictoire, L., Snyder, J., Stoolmiller, M., & Hollenstein, T. (2012). Affective dynamics in triadic peer interactions in early childhood. *Nonlinear Dynamics in Psychology and the Life Sciences*, 16(3), 293–312.
- LeBreton, J. M., & Senter, J. L. (2008). Answers to twenty questions about inter-rater reliability and inter-rater agreement. *Organizational Research Methods*, 11, 815–852. doi:10.1177/1094428106296642.
- Lewis, M. D., Lamey, A. V., & Douglas, L. (1999). A new dynamic systems method for the analysis of early socio-emotional development. *Developmental Science*, 2(4), 458–476. doi:10.1111/1467-7687.00090.
- Lizdek, I., Sadler, P., Woody, E., Ethier, N., & Malet, G. (2011). Capturing the stream of behavior: A computer joystick method for coding interpersonal behavior continuously over time. *Social Science Computer Review*, 1–9. doi:10.1177/0894439312436487.
- Locke, K. D., & Sadler, P. (2007). Self-efficacy, values and complementarity in dyadic interactions: integrating interpersonal and social-cognitive theory. *Personality and Social Psychology Bulletin*, 33(1), 94–109. doi:10.1177/0146167206293375.
- Lunkenheimer, E. S., & Dishion, T. J. (2009). Developmental psychopathology: Maladaptive and adaptive attractors in children’s close relationships. In S. J. Guastello, M. Koopmans, & D. Pincus (Eds.), *Chaos and complexity in psychology* (pp. 282–306). New York: Cambridge University Press.
- Mainhard, M. T., Brekelmans, M., den Brok, P., & Wubbels, T. (2011). The development of the classroom social climate during the first months of the school year. *Contemporary Educational Psychology*, 36(3), 190–200.
- Mainhard, M. T., Brekelmans, M., & Wubbels, T. (2011). Coercive and supportive teacher behaviour: within- and across-lesson associations with the classroom social climate. *Learning and Instruction*, 21(3), 345–354. doi:10.1016/j.learninstruc.2010.03.003.
- Mainhard, M. T., Pennings, H. J. M., Wubbels, T., & Brekelmans, M. (2012). Mapping control and affiliation in teacher–student interaction with state space grids. *Teaching and Teacher Education*, 28, 1027–1037. doi:10.1016/j.tate.2012.04.008.
- Markey, P. M., Lowmaster, S. E., & Eichler, W. C. (2010). A real-time assessment of interpersonal complementarity. Personal relationships. *Personal Relationships*, 17, 13–25. doi:10.1111/j.1475-6811.2010.01249.x.
- Maulana, R., Opendakker, M.-C., Den Brok, P., & Bosker, R. (2011). Teacher-student interpersonal relationships in Indonesia: Profiles and importance to student motivation. *Asia Pacific Journal of Education*, 31, 33–49. doi:10.1080/09243453.2011.619198.
- Pennings, H. J. M., Brekelmans, M., Wubbels, T., Van Der Want, A. C., Claessens, L. C. A., & Van Tartwijk, J. (2014). A nonlinear dynamical systems approach to real-time teacher behavior: Differences between Teachers. *Nonlinear Dynamics, Psychology, and Life Sciences*, 18(1), 23–45.
- Pennings, H. J. M., Mainhard, T., & Brekelmans, M. (2015). *Momentary teacher-student interactions and teacher interpersonal styles*. Paper (to be) presented at the 18th annual meeting of the Society for Interpersonal Theory and Research (SITAR) May 29–30, Toronto, Canada.
- Pennings, H. J. M., Van Tartwijk, J., Vermunt, J., & Brekelmans, M. (2012). *Leren en ontwikkeling van competenties van aanstaande, beginnende en ervaren docenten: Interpersoonlijk docentgedrag en leerlingbetrokkenheid* [Learning and developments of competencies of novice

- and expert teacher: Interpersonal behavior and student engagement]. Paper presented at the Onderwijs Research Dagen (ORD), juni 20-22, Wageningen, Nederland.
- Pennings, H. J. M., Van Tartwijk, J., Wubbels, T., Claessens, L. C. A., Van Der Want, A. C., & Brekelmans, M. (2014). Real-time teacher-student interactions: A dynamic systems approach. *Teaching and Teacher Education, 37*, 183–193.
- Prins, F. J., & Mainhard, M. T. (2012). *Development of a questionnaire on interpersonal student behavior (QISB) during feedback dialogues*. Paper presented at the meeting of EARLI SIG Assessment, 28–31 August, Brussels, Belgium.
- Roorda, D. L., Koomen, H. M. Y., Spilt, J. L., & Oort, F. J. (2011). The influence of affective teacher-student relationships on student's school engagement and achievement: A meta-analytic approach. *Review of Educational Research, 81*, 493–529. doi:[10.1007/s10648-011-9170-y](https://doi.org/10.1007/s10648-011-9170-y).
- Sadler, P., Ethier, N., Gunn, G. R., Duong, D., & Woody, E. (2009). Are we on the same wavelength? Interpersonal complementarity as shared cyclical patterns during interactions. *Journal of Personality and Social Psychology, 97*(6), 1005–1020. doi:[10.1037/a0016232](https://doi.org/10.1037/a0016232).
- Shannon, C. E., & Weaver, W. (1949). *The mathematical theory of communication*. Urbana, IL: University of Illinois Press.
- Skinner, E. A., & Belmont, M. J. (1993). Motivation in the classroom: Reciprocal effect of teacher behavior and student engagement across the school year. *Journal of Educational Psychology, 85*, 571–581.
- Skinner, E. A., Kindermann, T. A., & Furrer, C. J. (2009). A motivational perspective on engagement and disaffection. Conceptualization and assessment of children's behavioral and emotional participation in academic activities in the classroom. *Educational and Psychological Measurement, 69*, 493–525. doi:[10.1177/0013164408323233](https://doi.org/10.1177/0013164408323233).
- Spilt, J. L., Koomen, H. M. Y., & Thijs, J. T. (2011). Teacher well-being: The importance of teacher-student relationships. *Educational Psychology Review, 23*, 457–477. doi:[10.1007/s10648-011-9170-y](https://doi.org/10.1007/s10648-011-9170-y).
- Thelen, E., & Smith, L. B. (1998). *A dynamic system approach to the development of cognition and action* (3rd ed.). Cambridge, MA: MIT Press.
- Thomas, K. M., Hopwood, C. J., Woody, E., Ethier, N., & Sadler, P. (2014). Momentary assessment of interpersonal process in psychotherapy. *Journal of Counseling Psychology, 61* (1), 1–14. doi:[10.1037/a0034277](https://doi.org/10.1037/a0034277).
- Turner, J. C., Christensen, A., Kackar-Cam, H. Z., Trucano, M., & Fulmer, S. M. (2014). Enhancing students' engagement report of a 3-year intervention with middle school teachers. *American Educational Research Journal, 51*, 1195–1226.
- Turnnidge, J., Cote, J., Hollenstein, T., & Deakin, J. (2013). A direct observation of the dynamic content and structure of coach-athlete interactions in a model sport program. *Journal of Applied Sport Psychology, 26*(2), 225–240. doi:[10.1080/10413200.2013.821637](https://doi.org/10.1080/10413200.2013.821637).
- Valeski, T. N., & Stipek, D. (2001). Young children's feelings about school. *Child Development, 73*, 1198–1213. doi:[0009-3920/2001/7204-0016](https://doi.org/0009-3920/2001/7204-0016).
- Van de Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in teacher-student interaction: A decade of research. *Educational Psychology Review, 22*, 271–297. doi:[10.1007/s10648-010-9127-6](https://doi.org/10.1007/s10648-010-9127-6).
- Van Petegem, K., Creemers, B. P., Rossel, Y., & Aelterman, A. (2005). Relationships between teacher characteristics, interpersonal teacher behaviour and teacher wellbeing. *Journal of Classroom Interaction, 40*(2), 34–43.
- Vauras, M., Kinnunen, R., Kajamies, A., & Lehtinen, E. (2013). Interpersonal regulation in instructional interaction: A dynamic systems analysis of scaffolding. In S. Volet & M. Vauras (Eds.), *Interpersonal regulation of learning and motivation: Methodological advances* (pp. 125–146). London, UK: Routledge.
- Wentzel, K. (2012). Teacher-student relationships and adolescent competence at school. In T. Wubbels, P. Den Brok, J. Van Tartwijk, & J. Levy (Eds.), *Interpersonal relationships in*

- education: An overview of contemporary research* (pp. 19–36). Rotterdam, The Netherlands: Sense Publications.
- Woolfolk Hoy, A., & Weinstein, C. S. (2006). Students' and teachers' perspectives on classroom management. In C. Evertson & C. S. Weinstein (Eds.), *Handbook for classroom management: Research, practice, and contemporary issue* (pp. 181–220). Mahwah, NJ: Lawrence Erlbaum.
- Wubbels, T., Brekelmans, M., Den Brok, P., Levy, J., Mainhard, T., & Van Tartwijk, J. (2012). Let's make things better. In T. Wubbels, P. Den Brok, J. Van Tartwijk, & J. Levy (Eds.), *Interpersonal relationships in education: An overview of contemporary research* (pp. 225–250). Rotterdam: SENSE Publishers.
- Wubbels, T., Brekelmans, M., Den Brok, P., Wijsman, L., Mainhard, T., & Van Tartwijk, J. (2014). Teacher-student relationships and classroom management. In E. T. Emmer & E. J. Sabornie (Eds.), *Handbook of classroom management* (pp. 363–386). New York: Taylor & Francis.
- Wubbels, T., Brekelmans, M., Den Brok, P., & Van Tartwijk, J. (2006). An interpersonal perspective on classroom management in secondary classrooms in the Netherlands. In C. Evertson & C. Weinstein (Eds.), *Handbook of classroom management: Research practice and contemporary issues* (pp. 1161–1191). New York: Lawrence Erlbaum Associates.