



Research paper

Real-time teacher-student interactions: The dynamic interplay between need supportive teaching and student engagement over the course of one school year

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ABSTRACT

This study explored the relation between need supportive teaching and early adolescents' engagement in moment-to-moment interactions and the development of interactional patterns over time. A single case study was conducted on one teacher and her eighth grade classroom, using classroom video observations evenly spread over the course of one school year. Multilevel and State Space Grid analyses showed that what the teacher *did* (in terms of supporting feelings of autonomy, competence and relatedness) when interacting with her students mattered immediately for their engagement. Further, specific structural patterns of teacher-student interaction were found, both within lessons and over time.

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1. Introduction

Student engagement is considered as an important prerequisite for learning as it has been shown to contribute to the attainment of multiple positive learning outcomes, including academic achievement and educational aspirations (Lei et al., 2018; Pietarinen et al., 2014; Reeve & Lee, 2014; Wang & Eccles, 2011) and persistence in school (Henry et al., 2012; Wang & Fredricks, 2014). However, prior studies have shown that adolescents' engagement tends to decline in secondary education (Engels et al., 2020; Wang & Eccles, 2011; Wang et al., 2015), which makes this a particular important period for studying engagement and the ways in which it can be fostered. As early as 1993, Finn called for research to identify the "manipulable aspects of classroom . . . processes that encourage student engagement" (Finn, 1993, p. vii). In the social context of the classroom, teachers have a central position (Hornstra et al., 2018; Stroet et al., 2013). According to Pianta et al. (2012), the nature and quality of relationship interactions between teachers and students are critical for understanding student engagement. With the transition

to secondary education, the nature and role of these interactions change. Whereas in elementary or primary school students primarily built a relationship with one core classroom teacher, in secondary school they typically experience multiple teachers throughout the day (Roorda et al., 2011).

1.1. Student engagement and need supportive teaching

Student engagement refers to students' active involvement in their learning activities (Reeve, 2012). Engaged students express their active task involvement by showing focused attention, active, quick, and intense effort, verbal participation, persistence and positive emotion. Disengaged students, in contrast, show their passivity through dispersed attention, passive, slow, and minimal effort, verbal silence, helplessness or flat emotion (Connell & Wellborn, 1991; Reeve et al., 2004; Skinner et al., 2009).

Studies examining relationships between teaching behaviors and student engagement often find their roots in self-determination theory (SDT; Ryan & Deci, 2000). In SDT, it is assumed that students possess an innate curiosity about the environment and interest in learning and skill development. Characteristics of the social context of the classroom can, however, either support or undermine their engagement (Reeve, 2012; Stroet et al.,

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2015). Central in this theory is the idea that three fundamental psychological human needs exist: the need for autonomy, competence and relatedness. Teachers can foster their students' motivation and engagement by supporting these needs (Stroet, 2014).

Need supportive teaching involves the provision of autonomy support, structure, and involvement (Connell & Wellborn, 1991; Stroet et al., 2013). *Autonomy-supportive* teachers typically provide students with choice, by incorporating their needs, interests, and preferences into the lesson. They foster relevance, by identifying the value, meaning, use, benefit or importance of a task, lesson, or behavior or by providing students with a meaningful and realistic rationale when choice is constraint. Lastly, *autonomy-supportive* teachers show respect for students' feelings, thoughts, and perspectives. Teachers implement *structure* by offering clarity in guidelines and expectations, by encouraging students and by providing step-by-step guidance and (constructive, non-comparative) informational feedback. Teachers express their *involvement* by showing affection, communicating attunement (i.e., showing understanding of the students and of what is important for them), and ensuring dependability and availability to dedicate resources (e.g., time) to students in class. Autonomy support, structure, and involvement complement each other in their effect on students' general level of need satisfaction (Connell & Wellborn, 1991).

While these need supportive teaching behaviors are known to encourage students' engagement, need thwarting teaching behaviors may cause students to become more disengaged. Need thwarting teaching is characterized by the exertion of control, limited provision of clarity and guidance resulting in chaotic interactions, and being unfriendly or even rejecting students (Van den Berghe et al., 2016).

Many previous studies reported a positive association between the degree to which adolescents *perceive* their teachers as need supportive and their engagement (e.g., Assor et al., 2002; Collie et al., 2019; Otundo & Garn, 2019; Stroet et al., 2013; Zhen et al., 2018). There is a smaller body of studies available that have used standardized *observations* of need supportive teaching and student engagement rather than student or teacher reports. Third-person observations help obtain a clearer perspective on classroom reality (Olivier et al., 2021), as they can capture aspects of classroom behavior largely outside of teacher and student awareness (Pianta & Hamre, 2009). In existing observational studies with (early) adolescents, similar associations were found between observed or student-perceived engagement and observed need supportive teaching practices (Jang et al., 2010; Stroet et al., 2015; Van den Berghe et al., 2016) or, defined more broadly, teachers' observed instructional, social, emotional support and classroom organization (e.g., McKellar et al., 2020; Raphael et al., 2008; Rimm-Kaufman et al., 2015; Ruzek et al., 2016).

Although observational studies may provide a more complete depiction of what happens in the classroom, observational instruments still often aggregate teacher and student behavior, for instance by relating a summative measure of observed need supportive teaching behaviors to students' collective engagement (e.g., Jang et al., 2010; Van de Pol et al., 2010). This more 'product oriented' research (Lavelli et al., 2005) does not allow for inferences to be made on how teacher and student behaviors affect one another from *moment-to-moment* and how patterns of classroom interaction develop over time (Mainhard et al., 2012). At present, we still know relatively little about the underlying micro-level dynamics responsible for the development of more general behavioral styles or perceptions of need supportive teaching and student engagement in secondary education. This requires studies examining teaching practices in relation to student engagement at a more "granular level" (Pianta et al., 2012, p. 380). Therefore, the present

study focuses on the real-time, micro-level processes of teacher-student interaction from the theory of complex dynamical systems.

1.2. Teacher-student interaction as a complex dynamic system

The complex dynamic systems approach (Smith & Thelen, 1993; Steenbeek & van Geert, 2013) acknowledges the situatedness of teacher-student interactions as they occur in real-time (Turner & Christensen, 2020). Applying this approach to the classroom, learning and teaching are seen as hierarchically nested in time (Hollenstein, 2007). This means that changes in learning and teaching occur from the *real-time*, moment-to-moment (micro level) timescale to the long term (macro level) timescale. Within the present study, we consider the real-time (need supportive) teacher and (engaged) student behaviors within one-on-one interactions as the building blocks of relatively stable and predictable patterns of interaction, leading to specific outcomes such as the general styles of need supportive teaching and (collective) student engagement described in prior research.

Thus, in order to grasp the macro-level outcomes, we need to understand how teacher and student behaviors affect one another from moment-to-moment and how patterns of classroom interaction develop over time. This requires fine-grained information of real-time behavior (Lavelli et al., 2005). Therefore, the present study explores moment-to-moment, one-on-one teacher-student interactions by means of dense observations of the behaviors of one teacher and the students in her classroom throughout one school year. Videotaped observations are used as video offers a permanent record of teacher-student interactions and therefore allows a kind of access to fine-grained information about moment-to-moment dynamics that is not feasible to capture with live observation (Sherin & van Es, 2005).

The dynamic systems approach offers several key concepts that can be used to analyze real-time interaction. Moment-to-moment behaviors that occur in real-time are called *states* and the range of all possible states is called the *state space* (Hollenstein, 2007, 2013; Pennings & Hollenstein, 2020). In the present study, the state space consists of all behavioral combinations of a certain level of need supportive teaching and a certain level of student engagement.

Often only a few states tend to occur and recur with some regularity (Hollenstein, 2013). These recurrent states are called *attractors*. Attractors are relatively stable states a system prefers and is drawn toward. In other words, the attractor "pulls" the trajectory of the system toward those states. In contrast to attractors, there are *repellers*. Repellers represent behaviors that rarely occur (Hollenstein, 2013).

As an illustration, consider the kind of classroom interaction in which the teacher listens carefully to students and acknowledges their feelings, thoughts, and perspectives, provides step-by-step guidance when needed, and shows commitment to students' learning. When the teacher continues to demonstrate this behavior, this may elicit active effort and participation among students, which in turn may lead to satisfied teacher behavior. The more often the teacher approaches students in a way that supports their needs, the more easily students may get engaged, the more easily need supportive behavior by the teacher may be triggered (i.e., teacher-student attractor), and the less likely need thwarting teacher behavior and disengaged student behavior is triggered (i.e., teacher-student repellers). Within such a positive social climate, it is plausible that the teacher only needs to make a small effort to re-engage students who are distracted or show minimal effort. In other words, the attractor of positive interaction is likely to "pull" the trajectory of the classroom system to this state.

Given that a system can be conceptualized as consisting of

attractors and repellers, *variability* is an essential source of information on such a system. A system with several attractors of low-to-moderate strength will show more variable (i.e., less stable and predictable) behavior than a system with only one very strong (i.e., deep) attractor, since it takes considerably less energy to move in and out of the attractors in the former than in the latter (Hollenstein, 2013). High variability may be an expression of the teacher being able to adapt to variable levels of student engagement and 'pull' the students from less to more positive interaction states and vice versa. However, as Mainhard et al. (2012) point out, "high variability may also be caused by a teacher who is struggling to keep classroom processes on track" (p. 1031).

1.3. Analyzing interpersonal behaviors in teacher-student interactions

There is substantial research on teacher-student interactions in the secondary school context (e.g., Allen et al., 2013; Henry & Thorsen, 2021; Mainhard et al., 2011; Malmberg et al., 2010; Van Braak et al., 2021; Virtanen et al., 2019). However, there are only a few studies using a detailed, complex dynamic systems approach that report observing both teacher and student behavior and combining these to describe interactions. For example, some studies examined scaffolding (Kupers, van Dijk, & van Geert, 2015; Kupers et al., 2017; Kajamies, 2017; Vauras et al., 2013) and co-regulation of student autonomy (Kupers, van Dijk, van Geert, et al., 2015) in teacher-student interactions. Van Vondel et al. (2017) and Menninga et al. (2021) studied how scientific understanding of students was co-constructed in student-teacher interactions during science and technology lessons and how teacher-student dynamics change as a consequence of teachers' professionalization. Multiple studies have combined the dynamic systems approach with insights from interpersonal theory to examine the interplay between (micro-level) teacher-student interactions and (macro-level) teachers' interpersonal style (Pennings, Brekelmans, et al., 2014, 2014b; Pennings & Hollenstein, 2020) or the general classroom social climate (Mainhard et al., 2012; Pennings & Mainhard, 2016). By using attractors and variability as indicators for the quality of classroom interaction, these studies showed that characteristics of real-time interactions can discriminate between teachers with distinct interpersonal styles or teacher-student relationships.

To the best of our knowledge, Turner et al. (2014, 2020) are the only researchers who systematically studied patterns of teacher-student interactions (in secondary education) from a dynamic systems approach using observations of teachers' instructional strategies and related those to observed student engagement. The researchers observed six randomly selected teachers and their students four times a year for three years during a professional development intervention and coded teacher motivational support and student engagement. The unit of analysis was the activity setting (the type of activity, e.g., lecture/discussion, group work, individual seat work). Analyses of the dynamic patterns of teacher-student interaction revealed two distinct patterns: an "upward group" showing a pattern of increased teacher motivational support and reciprocal student engagement, and a "stable group" with teacher motivational support and student engagement showing stable or declining trajectories over three years. These results emphasize the importance of conceptualizing student engagement as an interpersonal classroom process and of measuring this process over time.

Turner et al. (2014, 2020) captured two related timescales of change: activity settings nested within lessons over the course of three years. In the present study, this work is further extended by zooming in on moment-to-moment teacher-student interactions

within lessons as the unit of analysis rather than activity settings. Furthermore, we investigate how these within-lesson interaction patterns might or might not change over the course of one school year. Interaction patterns are explored on two levels of increasing complexity: from the association between teacher and student behavior within one-on-one dyadic interactions to the structure (stability, variability) of these interactions.

1.4. Research questions

The main question of the present study is as follows: What moment-to-moment interactions (in terms of levels of need supportive teaching and student engagement) are most characteristic of one specific teacher-classroom system, and how do these interactions change over the course of one school year? This main question is divided into two sub-questions: 1. To what extent are the degree of need supportive teaching and student engagement related to each other in moment-to-moment interactions (i.e., on the micro-level timescale)? 2. How do teacher-student interactions change over the course of one school year in terms of their structure (i.e., on a macro-level timescale)?

2. Method

2.1. Participants

One secondary school teacher was selected from a larger sample of 11 teachers participating in a longitudinal study on differentiation in the Netherlands (Minnaert et al., 2016). The teachers in this larger sample worked in seven secondary public schools geographically spread across the country and taught the subject of either Dutch, English, or mathematics to 8th grade students. In the Dutch school system, this is the second year of secondary school following the transition from primary school. All classes were at the prevocational level. For the present study, the teacher with the fewest missing data (i.e., observed lessons) over the entire school year was selected. This teacher (female, 32 years old, with 6–10 years of teaching experience) taught the subject of Dutch language and literature to the students in the observed class. The class consisted of 21 students, 18 of whom participated in the study. Of these students, 61.9% were boys.

2.2. Procedure

The study was approved by the Ethics Committee of the Department of Pedagogical and Educational Sciences of the University of Groningen, The Netherlands. Informed consent was requested from the teacher, the participating students, and their parents. Consent was received for all except three students. Therefore, these three students were excluded from the study. All data from the study was pseudonymized and stored at a secured hard disk.

To observe teacher and student behavior, nine lessons were videotaped at three waves of data collection evenly spread over the course of the 2018–2019 academic school year. Each lesson was recorded with three cameras: (a) two cameras positioned at a fixed place in the classroom (one in front and the other in the back of the classroom) and (b) a bodycam, attached to the teacher's chest. For each of the nine lessons, all one-on-one interactions were identified, transcribed and coded in Excel. For this purpose, the bodycam recordings were used as standard, as through these recordings most one-on-one teacher-student interactions were clearly visible and audible. Only when the bodycam recordings did not provide sufficient information to code teacher and student behavior (e.g., when a student fell outside the bodycam's view), the recordings

from the fixed cameras were used. In practice, this was hardly required, with a maximum of two instances per lesson.

2.3. Measures

The videotaped lessons were coded using existing rating sheets for need supportive teaching (Stroet et al., 2014) and student engagement (Reeve et al., 2004). The unit of analysis was 'one-on-one teacher-student interaction'. An one-on-one teacher-student interaction was defined as the full conversation between a teacher and a student on one subject. An interaction started with the teacher addressing a student, or vice versa. An interaction ended with the student getting back to work, the teacher walking away from the student's seat or the teacher addressing another student. Lessons typically included episodes of whole class teaching and students working individually or in small groups. Every one-on-one teacher student interaction was coded on each of the three dimensions of need supportive teaching (autonomy support versus autonomy thwart, structure versus chaos, and involvement versus disaffection or rejection) and on student engagement (versus disengagement). In the case of a behavioral correction (e.g., "Please be quiet!"), the interaction was classified as not being relevant in terms of providing structure versus chaos; autonomy support and involvement were still coded for such interactions. If a teacher-student interaction could not be coded (e.g., because it was inaudible), the label 'no code' was applied; in practice this rarely occurred. The video fragments of interactions to which codes referred were time-stamped. However, information on the duration of interactions was not addressed in the present study, and is therefore not discussed further here.

Table 1 lists the dimensions and corresponding components of need supportive versus need thwarting teaching and student (dis)engagement.

Table 1
Components of need supportive versus need thwarting teaching and student (dis)engagement.

Dimension	Positive component	vs. Negative component	Example interaction of the most positive score (+3)	Example interaction of the most negative score (-3)
Teacher autonomy support/thwart	Choice Fostering relevance Showing respect	Control Forcing meaningless activities Showing disrespect	A student talks about an alternative way to get to the answer to an assignment. The teacher replies: "You may do it this way, but it will take you longer in the end. Why, do you think?" (autonomy support, code +3)	The teacher responds to a student's comment that they have already covered a particular topic in previous lessons with: "Stop, I don't want to have this discussion with you. You just do what I ask of you". (autonomy thwart, code -3)
Teacher provision of structure/chaos	Clarity (in instructions) Guidance Encouragement Informational feedback	No clarity (in instructions) No guidance Discouragement Evaluative feedback	The teacher actively walks around the classroom and asks a student: "Do you understand the assignment?". The teacher has the student explain where in the assignment she got stuck and then provides step-by-step directions, adjusting to the student's comprehension. (structure, code: +3)	A student asks what she is supposed to do. The teacher replies: "I don't want to hear any questions yet. I just explained it... Your classmates did understand". (chaos, code: -3)
Teacher involvement/disaffection or rejection	Affection Attunement Dedication of resources Dependability	Disaffection No attunement No dedication of resources No dependability	The teacher asks a student: "Tomorrow you are going to the cinema, right? I hope you will enjoy the movie!". She then tells a personal story herself about a movie she watched at the cinema the other day and continues to talk with the student about their favorite movies. (involvement, code +3)	The teacher says in an unfriendly, disapproving tone: "You are irritating me". (disaffection, code: -3)
Student engagement/disengagement	Focused attention Active, quick, intense effort Verbally participating Persists Positive emotional tone	Dispersed attention Passive, slow, minimal effort Verbally silent Gives up easily Flat emotional tone	A student looks at the teacher, asks questions, checks his understanding, and gets to work. (engagement, code +3)	The teacher asks a student why he has a phone in his hand. The student stays busy on the phone and does not respond to the teacher. The teacher asks the student to put the phone away and go do the assignment. The student now responds, "Oh and then what is he doing?" while pointing to another student who is also on his phone. (disengagement, code: -3)

Note. For a more detailed description of the components of need supportive teaching and student engagement and an overview of the literature grounding their operationalization, see Stroet et al. (2014) and Reeve et al. (2004), respectively.

was calculated for the interactions where this was true and therefore were assigned a code. Cohen's k for the first step was .93 and the ICC for step 2 was 0.92. Given that the inter-observer agreement proved sufficient, the remaining data was coded by the first author.

To answer research question 1, the scores assigned to each of the three dimensions of need supportive teaching during coding were averaged, resulting in one overall score for need supportive teaching for each one-on-one teacher-student interaction. By this aggregation, it was possible to analyze overall need support as a characteristic of real-time interactions. For student engagement, an overall score was already assigned during the coding process. To answer research question 2, the overall scores for need supportive teaching and student engagement were recoded into five categories: (1) *strongly negative* (consisting of all interactions with scores from -3 to -2), (2) *moderately negative* (scores -1 to 0), (3) *neutral* (score 0), (4) *moderately positive* (scores 0 to 1), and *strongly positive* (scores 2 to 3). Thus, here need supportive teaching ranged from level 1/very need thwarting behavior to level 5/very need supportive behavior. Student engagement ranged from level 1/very disengaged to level 5/very engaged behavior.

2.4. Analyses

Analyses were performed on a total of 794 interactions, which were nested in 9 lessons (range of 66–124 one-on-one interactions per lesson) and 18 students (range of 9–102 one-on-one interactions per student).

2.4.1. Research question 1

We used multilevel modeling (in SPSS, version 26) to examine the relationship between the degree of need supportive teaching and student engagement within moment-to-moment interactions. As our data had an inherent hierarchical structure with interactions nested within students and within lessons, this analysis was needed to limit the possible bias resulting from the dependency of the observations (Snijders & Bosker, 1999). We computed two separate models, based on repeated measures: one for interactions nested in students and one for interactions nested in lessons. Thus, both analyses involved a two-level hierarchy with interactions at the first level and students and lessons, respectively, at the second level.

We began both analyses with an unconditional (random intercept) model of the variation in student engagement. This model allowed us to determine if interactions for the same student or interactions within the same lesson were more alike than interactions from different students or lessons. The results indicated only significant variation in engagement among students, not among lessons. Therefore, only for this model (i.e., interactions nested within students) we proceeded our multilevel analysis to explain this variation as a function of need supportive teaching. We added explanatory variables as fixed effects to examine whether these were associated with student engagement within one-on-one interactions. Following recommendations by Snijders & Bosker (1999), we included as predictors both the degree of need supportive teaching within interactions and the average degree of need supportive teaching per student over all measurement occasions. For both independent variables, group mean centering was applied. Lastly, we tested for random slope variance to determine whether there were differences between students in the extent to which need supportive teaching played a role in explaining their student engagement within one-on-one interactions.

2.4.2. Research question 2

To study the dynamic aspects of need supportive teaching and

student engagement within teacher-student interactions we used State Space Grid (SSG) analysis (Hollenstein, 2013; Lewis et al., 1999) and the corresponding program GridWare 1.1 (Lamey et al., 2004). The combinations of the categories of teacher and student behavior were plotted against each other in a SSG, creating a visual representation of interactional behavior within one-on-one interactions. The cells in the grid represent states, i.e., all possible combinations of participant behavior (e.g., level 5/strongly positive need supportive teaching, level 5/strongly positive student engagement). Each one-on-one interaction is registered on the grid with a dot. Thus, each dot on the grid captures the teacher's level of observed need supportive teaching in interaction and, simultaneously, the corresponding level of observed engagement by the student. For example, in Fig. 1, cell 34 (x/y convention) represents a state of neutral (i.e., not positive, not negative) need supportive teaching and moderately positive student engagement. A line is drawn from dot to dot, displaying the sequence of dyadic states.

The structure of these teacher-student interactions and changes across the school year were studied in two ways: by examining 1) attractors and 2) variability. First, for each lesson, after preliminary visual inspection, attractors were detected empirically using the winnowing method¹ as described in Hollenstein (2013) and Lewis et al. (1999). Second, for the analysis of variability in interactions, levels of dispersion were calculated for each lesson. Dispersion is a whole-grid measure that indicates to what extent dyadic behaviors are distributed across the SSG and is expressed in a value between 0 (no variability; all interactions are in one cell of the grid) and 1 (maximum variability; all interactions are equally spread out over the grid). Levels of dispersion for each of the nine lessons were plotted over time and the trend was tested non-parametrically using a Monte Carlo (MC) test, which compares the slope of the empirical data with the average slope of 10,000 times randomly shuffled data.

3. Results

3.1. Relation between the degree of need supportive teaching and student engagement within moment-to-moment interactions (i.e., the micro-level timescale)

3.1.1. Assumptions

The outcomes of the tests on the assumptions underlying the multilevel regression model showed that the assumption of equal variance of residuals across groups and the assumption that level-2 errors should not correlate with each other were violated. Therefore, it is important to interpret the results that are discussed below with caution.

3.1.2. Interactions nested in students

As shown in Table 2, the results for the unconditional model revealed significant variation in engagement among students. From the results, we calculated the intraclass correlation coefficient, which indicated that 8.6% of the total variance in student engagement could be attributed to differences between students. Thus, most differences in student engagement were still due to differences between interactions, instead of differences between students.

However, given that student engagement did vary significantly

¹ For an elaborate description of this procedure we refer to Hollenstein (2013). In short, this method differentiates inconsequential variation from systematic variation reflecting the underlying structure of a system. In other words, when using this method, the formal and compelling foundation for an attractor state is that it is more probable than other states.

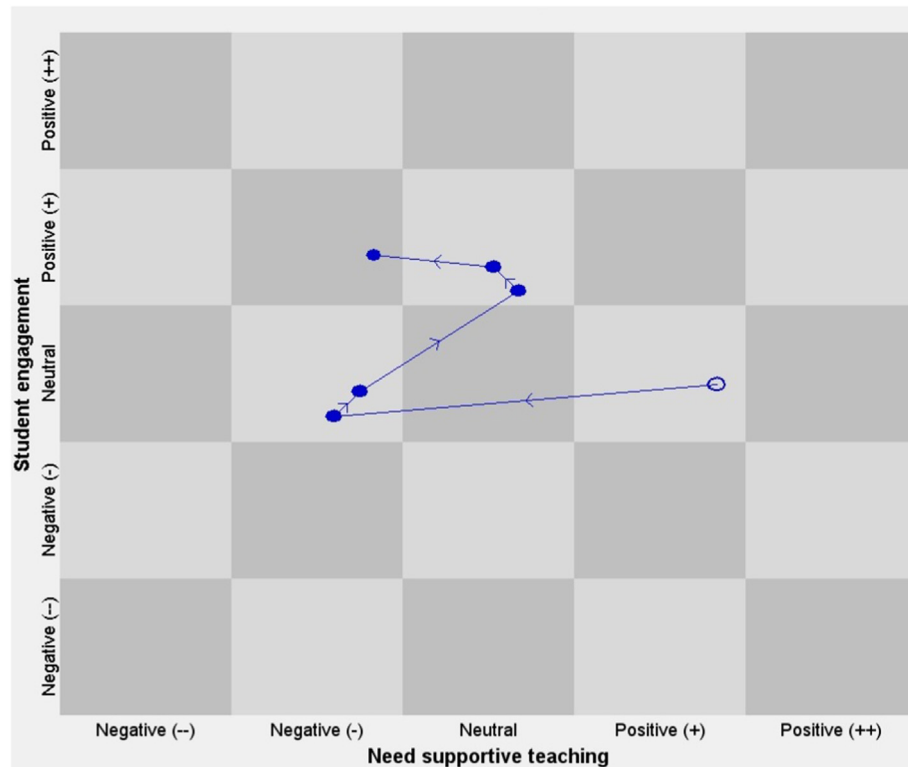


Fig. 1. Example State Space Grid. *Note.* This is a hypothetical example of several one-on-one teacher-student interactions, and is solely designed to illustrate what a State Space Grid looks like. The X-axis represents teacher behavior (level of need supportive teaching) and the Y-axis represents student behavior (student engagement). The opaque dot represents the start of the interaction trajectory; the arrow line the change in dyadic behavioral states over the course of a few interactions. The position of a dot in a cell is arbitrary.

Table 2

Model estimates for between-student variation in (the effects of need supportive teaching and average need supportive teaching per student on) student engagement (794 interactions nested in 18 students).

Model	Unconditional model			Model 1 (final model)		
	Coefficient	SE	95% CI	Coefficient	SE	95% CI
Fixed part						
Intercept	.528**	.066	[.390, .666]	.538**	.044	[.446, .631]
Need supportive teaching				.303**	.035	[.235, .372]
Average need supportive teaching				.737**	.154	[.417, 1.056]
Random part	Variance	SE	95% CI	Variance	SE	95% CI
Student level	.059*	.025	[.026, .134]	.018	.011	[.006, .058]
Interaction level	.628**	.032	[.569, .695]	.572**	.029	[.517, .632]

* $p < .05$; ** $p < .001$.

among students, we continued by adding independent variables as fixed effects to explain that variation. As shown in Table 2, the results for Model 1 indicated that observed need supportive teaching was significant for observed student engagement within one-on-one interactions. Thus, in general, the more the teacher demonstrated need supportive behaviors in any one-on-one interaction, the more the student with whom she interacted showed engagement in that same interaction. Remarkable is the fact that the contextual effect of the average degree of need supportive teaching per student made an unique contribution above the effect of the degree of need supportive teaching within interactions. This indicates that an interaction with a given degree of need supportive teaching was, on average, associated with higher student engagement if this interaction 'belonged' to a student with a higher degree of average need supportive teaching.

Next, we tested for random slope variance, but this was not significant. Thus, the effect of need supportive teaching on student

engagement within interactions did not differ among students. Therefore, the random slope model is not presented in Table 2. The model with a random intercept and fixed effects was chosen as the final model.

3.1.3. Interactions nested in lessons

As shown in Table 3, the results for the unconditional model revealed no statistically significant variation in engagement among lessons. Thus, we got no indication that the average score for student engagement differed significantly between lessons: interactions within lessons were no more similar than interactions from different lessons. In other words, engagement did not seem to be a lesson characteristic in this classroom.

Because the degree of student engagement appeared to be independent of lessons, no subsequent models were constructed and the unconditional model was interpreted as the final model.

Table 3

Model estimates for between-lesson variation in student engagement (794 interactions nested in 9 lessons).

Model	Unconditional (final) model		
	Coefficient	SE	95% CI
Fixed part			
Intercept	.557**	.041	[.465, .650]
Random part			
Lesson level	Variance	SE	95% CI
	.005	.007	[.000, .074]
Interaction level	.690**	.035	[.624, .763]

* $p < .05$; ** $p < .001$.

3.2. Changes in the structure of teacher-student interactions over the course of one school year (i.e., the macro-level timescale)

3.2.1. Attractors

Fig. 2 shows for each of the nine lessons the dyadic behaviors of all one-on-one teacher-student interactions within that lesson. Each dot on the grid represents a one-on-one teacher-student interaction and simultaneously captures the teacher's level of need supportive teaching and the student's level of engagement observed within that interaction. Visual inspection showed that many dyadic behaviors were observed (i.e., there are dots in many cells of the SSGs), but some interactions were absent or occurred rarely. For example, interactions rarely took place within the areas combining moderately or strongly positive levels of need supportive teaching (x_4, x_5) with moderately or strongly negative levels of student engagement (y_1, y_2). Thus, (strongly) need supportive teacher behavior in any one-on-one interaction hardly seemed to go hand-in-hand with (strongly) disengaged student behavior in that same interaction. Those interactions could be identified as repellors. An example of such a repeller interaction is when the teacher hands out answer sheets. There appear to be fewer answer sheet than students. A student quickly grabs an answer sheet, to which the teacher responds: "You grabbed it nice and fast, but your neighbor [i.e., the student next to the student in question] can't see anything now, can he?". The student responds toward the student next to him: "Good for you". The teacher remarks: "There are only two answer sheets per group" and walks on. In this brief interaction, the teacher promotes a cooperative learning structure and encourages prosocial behavior in the class (thereby providing structure and involvement), which the student does not immediately respond to with effort and cooperation, but with a slightly passive comment instead.

The densely clustered dots in the SSGs show that, within this classroom, teacher-student interactions were mostly characterized by a combination of moderately negative to moderately positive need supportive teacher behavior and moderately negative to moderately positive engaged student behavior. The empirically identified attractors derived from the winnowing procedure (see Analysis section) show for each lesson which combination of teacher and student behavior occurred most frequently in one-on-one interactions. All lessons had apparent attractors. These attractors are marked in yellow in Fig. 2 and could consist of either one cell or of two or more adjacent cells. For example, lesson 7 showed two separate attractors, whereas lesson 9 was remarkable due to its large attractor region (constituting of six cells).

After primary attractors were identified on the first winnowing series, often considerable heterogeneity among the remaining cells was found. Some had a relatively high amount of dots, showing that although the combinations of teacher and student behavior represented by these cells may not have been the most prevalent in one-to-one interactions, they were still frequent. Hence, these cells were candidates for secondary, less powerful attractors. In all

lessons, except lesson 9, this seemed possible based on visual inspection. Therefore, for those lessons the identified attractors were removed from the analysis (i.e., they were set to zero) and the winnowing procedure was repeated to test for other attractors. For each of the remaining lessons one or more secondary attractors were indeed found. In the grids, these secondary attractors are colored in blue.

Overall, cell 44 stood out as a preferred state to which interactions were drawn. One-on-one teacher-student interactions projected largely into this favorable state. This state indicated complementarity of interaction: a combination of moderately positive need supportive teacher behavior and moderately positive engaged student behavior. An example of such an attractor interaction is when the teacher approaches a student who has not yet started her school work. The teacher says: "Um, you are supposed to start with chapter two". The student does not yet make eye contact and only responds with "yes". The teacher continues to ask: "Have you done that yet?". The student points in the book and says: "This is chapter 2". The teacher repeats: "Yes, and have you started it yet?". The student answers that she has not, while now also making eye contact with the teacher. The teacher responds, in a friendly tone: "Maybe you should go do that". The student smiles. The teacher continues: "Because the other students have also already started and otherwise you will fall behind. So now you get to work too, okay?" The student replies: "Yes, I will". The teacher raises her thumb and walks on. In this interaction, the teacher is quite directive (i.e., she actively attempts to push the student to get to work), but provides a meaningful and realistic rationale for doing so. She demands effort from the student and demonstrates involvement by monitoring the student's learning process. The student is still somewhat unengaged during the first part of the interaction, but eventually gets to work at the end of the interaction. This state combining this kind of interaction of moderately positive need supportive teacher behavior and moderately positive engaged student behavior was an attractor in all lessons, showing the stability of this attractor throughout the school year.

In the first three lessons and in lesson 6 state 44 was the only (primary) attractor interactions were drawn toward. Thus, in these lessons, relatively positive teacher-student interaction was predominant. In the other lessons, attractor state 44 was supplemented with one or multiple additional attractor states the system was drawn toward. Thus, in these lessons one-on-one teacher-student interactions were rooted in multiple, rather than one, stable states. What is noteworthy here is that these states did not always show complementarity of interaction. Even when teacher behavior was attracted to moderately negative levels of need supportive teaching, this was more likely to be associated with neutral or moderately positive student engagement than with negative student engagement.

3.2.2. Variability

The SSGs yielded high levels of dispersion (between 0.905 and 0.943 on a scale of 0–1, with an average level of 0.919). This means that in general, the interactions within a lesson were characterized by high flexibility. The dispersion stayed remarkably stable over time, with the same high values throughout the time series (see Fig. 3). Indeed, no significant decrease was found over time ($p = .282$).

4. Discussion

The purpose of the present study was to explore need supportive teaching and secondary school students' engagement within real-time interactions. In order to do this, both the relation between need supportive teaching and student engagement within

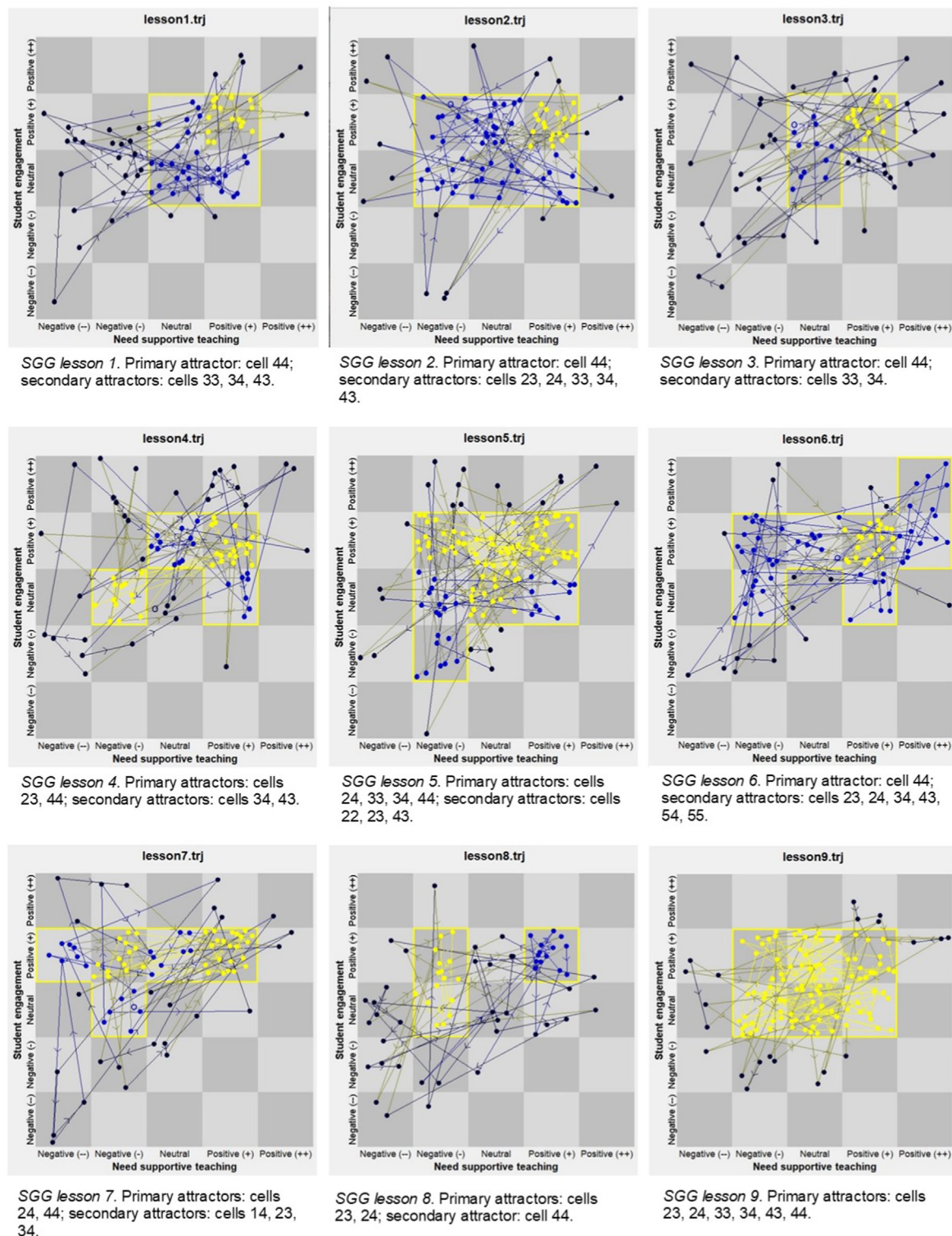


Fig. 2. State Space Grids (SGGs) lesson 1 to lesson 9.

moment-to-moment interactions and the expression and development of interactional patterns over the course of one school year were explored. The main question was: *What moment-to-moment interactions (in terms of need supportive teaching and student engagement) are most characteristic of one specific teacher-classroom system, and how do these interactions change over the course of one school year?*

4.1. The relation between the degree of need supportive teaching and student engagement within moment-to-moment interactions

Although the results did show significant differences between students in terms of their average degree of observed student engagement, it appeared that most of the differences in student engagement were still due to differences between interactions,

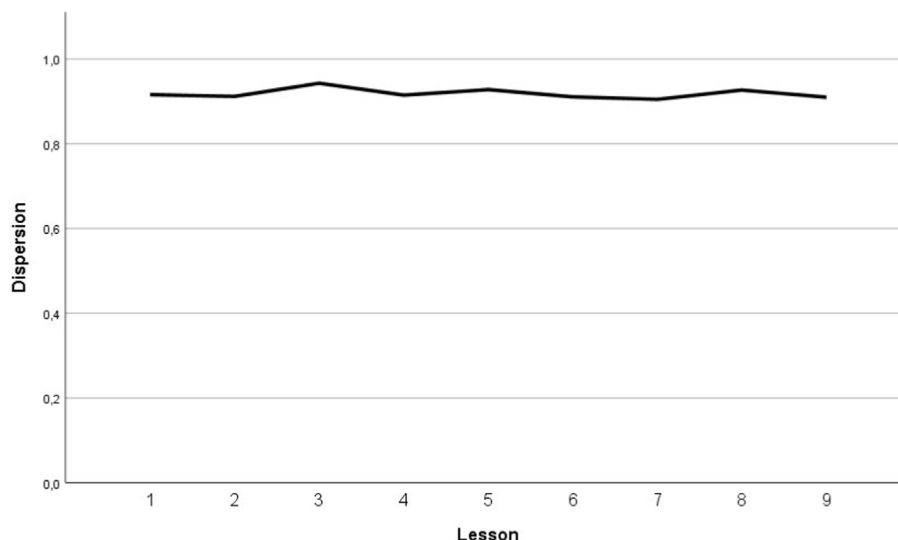


Fig. 3. Levels of Dispersion over time.

rather than differences between students. Thus, a student's engagement could be (positively or negatively) affected in each and every one-on-one interaction. Apparently, for the students in this class, context was still of great importance for their engagement. This is in line with [Reeve's \(2012\)](#) emphasis on the role of context in explaining engagement, outlining how students live and interact in a dynamic, social system that offers supports and threats to their engagement. Reeve even stresses that since

in the classroom, the teacher and the learning environment are so instrumental in supporting versus frustrating student motivation and engagement [...], it almost does not make sense to refer to "student" engagement because it cannot be separated or disentangled from the social context in which it occurs (p. 152).

The results indicated the same positive association between observed need supportive teaching and observed student engagement on the lower, micro-level timescale of moment-to-moment interactions as [Jang et al. \(2010\)](#), [Stroet et al. \(2015\)](#), and [Van den Berghe et al. \(2016\)](#) found with more global measures summarizing observed teacher and/or student behavior. Thus, within one-on-one interactions, an increase in the observed degree of need support by the teacher was related to an increase in the observed degree of student engagement. In other words, when the teacher supported feelings of autonomy, competence and/or relatedness with her behavior in any one-on-one interaction, it was generally associated with the student being more fully dedicated and more genuinely engaged within that same one-on-one interaction.

In addition to this effect of the degree of need supportive teaching within an interaction, the contextual effect of the average degree of need supportive teaching per student also appeared to make a unique contribution. Apparently, for the degree of engagement of a student within any one-on-one interaction not only the teacher's need supportive practices during that specific interaction were important, but also her more general style of need supportive teaching to the student in question. It is possible that we see the dynamic systems principle of the coupling of timescales expressed here ([Hollenstein, 2013](#)), with general style of need supportive teaching acting as a more stabilized (i.e., macro-level) trait of how the teacher and a particular student *usually* interact. This global pattern of interaction may 'constrain' behaviors within real-time (i.e., micro-level) one-on-one interactions - perhaps

through the role of expectations in the prediction of behavior ([Skinner & Belmont, 1993](#)).

Important to note is that, due to the design for answering the first research question being correlational, the results do not justify the conclusion that teachers' need supportive behaviors enhance students' engagement. As [Van den Berghe et al. \(2016\)](#) also indicate, the relationship is likely to be bi-directional. That is, teachers' need support could enhance students' engagement, but it is equally likely that students' active engagement could enhance teachers' provision of need support ([Reeve et al., 2004](#); [Van den Berghe et al., 2016](#)). For example, studies showed that teachers were more need supportive when they held more positive beliefs about their students' motivation ([Pelletier et al., 2002](#)) and that, conversely, student disengagement elicited more need-thwarting behavior ([Van den Berghe et al., 2015](#)). Therefore, a one-way route from teacher behavior to student learning seems to oversimplify the complexity of teacher-student interactions. On the other hand, however, there is evidence for, in general, the teacher being in charge of what happens in the classroom. [Mainhard et al. \(2012\)](#) and [Pennings, van Tartwijk, et al. \(2014\)](#) found that interaction in secondary classrooms was, most of the time, dominated by more teacher than student control. Moreover, teacher-student interactions were characterized by complementarity: dominant behavior by the teacher most probably invited contrasting, submissive student responses. Without wanting to underestimate the likelihood of reciprocal effects of teacher behavior and student engagement, this to some extent justifies the decision in the present study to perceive the teacher as leading the interaction and therefore student engagement as influenced by the degree of need supportive teaching by the teacher.

4.2. Changes in the structure of teacher-student interactions over the course of one school year

SSGs were used as a way of graphically representing the teacher and her students as interlocking parts of a "network of interdependency that in itself will be moving and changing over time" ([Mainhard et al., 2012, p. 1028](#)). Based on dynamic systems theory and SDT, it was expected that teacher-student interactions would converge to specific regions of the state space, namely the regions at the intersection of corresponding levels of need supportive teaching and student engagement. Indeed, it appeared that in all

lessons interaction was drawn toward the state of moderately positive need supportive teaching and moderately positive student engagement. This state being located at the intersection of corresponding levels of teacher and student behavior confirms the expectation of complementarity in interaction. Thus, as predicted by the SDT, moderately positive teacher behavior tended to invite reciprocal student behavior.

In all lessons this stable attractor state was supplemented with a few or relatively many additional (primary or secondary, less powerful) attractor states the system was drawn toward. This corresponds with the remark by Lamey et al. (2004) that living systems are characterized by *multistability*. That is, their state space includes several co-existing attractors and “contextual constraints probabilistically guide behavior toward a particular attractor at any given moment in time” (p. 37). In other words, each lesson contains some stable and recurrent interaction patterns and contextual conditions at the time of any one-on-one teacher-student interaction increase or decrease the likelihood that the content of that interaction with indeed match one of these patterns.

Some of these additional attractors were characterized by complementarity in interaction, whereas others were not. In the latter case, there appeared to be a trend of student behavior inclined to be attracted to more favorable states than would be expected on the basis of complementarity of interaction. Even when the teacher's behavior in an interaction undermined feelings of autonomy, competence, and relatedness to some degree (i.e., was need-thwarting), the student with whom she interacted was still more likely to show neutral or moderately positive engagement than negative engagement. A possible explanation may be that, at least within the short term (i.e., within one-on-one interactions), certain need thwarting behaviors are also conducive to students' engagement. For example, it could be that students react with enhanced engagement on getting a straightforward answer from the teacher, perhaps even more so when they consider the need supportive alternative (e.g., sharing and discussing their own thoughts on the solution) as irritating or hindering the speed of their progress on the learning task.

As to variability, for this classroom, rather than a trend from initial unpredictable interaction patterns at the beginning of the school year to increased stabilization as the year proceeds, interaction remained strongly dispersed across the grid throughout the year. Variability offers flexibility and room for exploration; it allows a system (in the present study that of the teacher and the students in her classroom) to explore different ways of adapting to one another (Thelen & Smith, 1994; Van Dijk & van Geert, 2015). Therefore, the stable, high variability found may be an expression of a high degree of context dependency and exploration in this classroom. In other words: teacher- and student interactions remained adaptive and reactive to variable circumstances. The findings of studies on the role of intra-individual variability point in different directions. In parent-child interactions less variability was related to negative emotions and child internalizing and externalizing problems (Hollenstein et al., 2004; Hollenstein & Lewis, 2006), whereas in classroom interactions, conversely, less variability was associated with more favorable teacher interpersonal styles (Pennings, Brekelmans, et al., 2014; Pennings & Hollenstein, 2020) and social climate (Mainhard et al., 2012). The latter contradicts the pattern in the present study, where high variability went hand in hand with predominantly positive teacher-student interaction. Comparing both studies suggests that the exact role of variability as a characteristic of classroom social climates may depend on the topic of the study and the timing of measurements.

Important to note is that within the present study, variability provided a representation of short-term behavioral fluctuations that were observed over interactions. Thus, the development of

variability was explored for the entire system of all teacher-student dyads in the classroom collectively, not for individual teacher-student dyads. However, interindividual differences in intra-individual variability exist (Van Dijk & van Geert, 2015): some individual students may have stabilized more quickly than others, some students may have developed more gradually, and others more discontinuously. It is unclear to what extent the description of variability in the present study provides a valid representation of all these unique trajectories.

4.3. Limitations and suggestions for future research

The present study has some limitations that should be taken into account in future studies. First, this was an exploratory study that only examined need supportive teaching and student engagement in moment-to-moment interactions for one teacher and her classroom. To fully understand the discriminant validity of real-time need supportive teaching and student engagement, these characteristics should be compared in interactions of teachers with other, preferably contrasting, general styles of need supportive (or need thwarting) behavior than in the present study. Understanding the discriminant validity of characteristics of real-time interactions is a prerequisite for studying the relation between real-time (micro-level) and developmental time (macro-level) processes (Pennings, van Tartwijk, et al., 2014). As a next step, studies may relate characteristics of real-time interactions to other, more contextual characteristics known to influence teachers' interpersonal behavior, e.g., their teaching experience (Wubbels et al., 2011) or their students' cultural backgrounds (Den Brok & Levy, 2005; Wubbels et al., 2006).

Second, two assumptions underlying the multilevel regression model were violated. It is therefore important to interpret the results relating to the first research question with caution. However, these violations are interesting by themselves. The first violation, of the assumption of equal variance of residuals across groups, may mean that within the present study variance was dependent on another, yet unknown (level-two) variable (Snijders & Bosker, 1999), such that, for example, students with a certain characteristic differed more from each other than students without that characteristic. In the present study, the explanation for differences in student engagement was sought only in the most proximate (i.e., micro-level) context of teacher behavior, i.e., *how* the teacher interacted with her students in one-on-one interactions. Other potentially important, more “higher-level” contextual factors were not addressed in the analyses. The second violation involved correlating errors at the level of students: some students were more similar than others. Referring again to the important role of context in explaining engagement (Reeve, 2012), it is theoretically quite plausible that students influence each other (positively or negatively) in terms of engagement. Inspection of the correlations, however, showed that the correlations found could not easily be explained by physical proximity in the classroom (i.e., the students who were more alike were generally not seated directly next to each other). It is important to have future research further explore explanations for the above observations, by applying the multilevel models on a larger scale and by incorporating more variables, including relevant controls and moderators.

Third, within the present study there were substantial differences between students in the number of one-on-one interactions with the teacher: some students clearly interacted with the teacher more often than others. There is a plausible risk that these differences were not entirely random. Skinner and Belmont (1993) state that “teachers are likely to modify their behavior toward individual children on the basis of their perceptions of the students' behavioral and emotional engagement” (p. 573). In this sense, two

explanations for the differences found are possible. On the one hand, the teacher may have had a 'preference' for interacting with students who were relatively less engaged, with the aim of re-engaging them. On the other hand, it is possible that the teacher responded to her students in ways that confirmed their initial engagement, thus interacting less with students who are passive and show negative emotion and vice versa. In order to gain more insight into these processes, future studies could supplement SDT with planned behavior theory, which outlines the relationship between attitudes, subjective norms, perceived behavioral control, behavioral intention and actual behavior (Ajzen, 1991). This may help understand why teachers are inclined to hinder or foster students' psychological needs and examine what teacher attitudes, norms and perceived behavior control make certain interaction patterns more likely than others.

Last, only the general level of need supportive teaching has been addressed in the present study. However, fulfillment of the basic psychological needs for autonomy, competence, and relatedness has been found to have unique additive effects on psychological well-being (Ryan & Deci, 2000). Further, people who experience balanced need satisfaction report higher well-being than those with the same sum score who reported greater variability in need satisfaction (Sheldon & Niemiec, 2006). Therefore, future research could focus on understanding the discriminant validity of the three dimensions of need supportive teaching and their relative importance for student engagement within one-on-one interactions.

4.4. Practical implications

Perhaps the most important lesson to be learned from this study is related to the situatedness of teacher-student interactions as they occur in real-time. Some teachers see the classroom atmosphere as largely resulting from students' characteristics and contextual factors (e.g., school culture; Ghafarpour & Moinszadeh, 2020). However, the study presented in this paper showed that, for the teacher-classroom system central to this study, what the teacher *did* when interacting with her students mattered immediately for their engagement. Our findings suggest that when a teacher supports feelings of autonomy, competence and/or relatedness within one-on-one teacher-student interaction, this increases the likelihood of the student being more fully dedicated and more genuinely engaged in the learning activity, during that very same interaction. Since this study is exploratory in nature, we must be cautious in making targeted recommendations for teaching and teacher education practice. If future research confirms differences in interactions between teachers with lower and higher levels of need supportive teaching, the message for practitioners becomes more powerful.

In the meantime, the dimensions of the codebook used may already offer insights that can support teachers in targeting their professional development goals towards enhancing student engagement. We know that seeing the effect of their behavior on students, increases teachers' motivation to learn or change (Tripp & Rich, 2012). Analyzing and discussing videotapes to facilitate reflection is a widespread practice in teacher education and professional development (Tripp & Rich, 2012). The SSG methodology may be suitable to complement existing practices. For example, preservice and inservice teachers can be provided with a detailed record of the sequential steps in their interactions with a specific student or in a particular lesson or teaching situation. The SSGs can be used to recognize and diagnose both optimal and non-optimal patterns and both "matches" and "mismatches" between teacher-offered opportunities for engagement and student uptake (Turner et al., 2014). It allows for detailed analysis of what a teacher did and how it was followed or preceded by student behavior.

Furthermore, one can extract moments where an interaction moves out of the preferable states and discuss reasons for this (Mainhard et al., 2012).

Altogether, observational data of moment-to-moment interactions, whether plotted on SSGs or otherwise analyzed, can be used to help preservice and inservice teachers *learn to notice* (e.g., Sherin & van Es, 2005) and *interpret* what is happening with the students in their classrooms in terms of engagement. We hope that our study has raised awareness among teachers and teacher educators of its value in understanding the mutual responsiveness of teacher and student activity.

5. Conclusion

The present study was an exploratory study on characteristics of moment-to-moment teacher-student interactions, in terms of levels of need supportive teaching and student engagement. More specifically, it provided initial insights into how need supportive teacher and engaged student behaviors relate to one another in real-time and how patterns of classroom interaction develop over time. Overall, the findings showed that, in the teacher-classroom system central to the present study, within one-on-one interactions, need supportive behavior by the teacher was associated with students being more engaged. Furthermore, specific structural patterns of teacher-student interaction were found, both within lessons and over time. In all lessons interaction was drawn toward a combination of moderately positive need supportive teaching and moderately positive student engagement. However, interaction remained strongly flexible throughout the year as well.

Using fine-grained information of real-time behavior, this study was a first step in studying teacher-student interactions in terms of need supportive teaching and student engagement as a micro-level process. The next step is to increase the number of teachers to study the discriminant validity of need supportive behaviors within one-on-one interactions. Ultimately, it is important to link real-time characteristics of teacher-student interaction to student and teacher macro-level characteristics and outcomes. Knowledge of these reciprocally causal processes contributes to a better understanding of why student engagement tends to decline in secondary education and provides directions for intervention and changing behavior in the classroom to improve student engagement and, more generally, teacher-student relationships and the classroom climate.

Data availability

The authors do not have permission to share data.

References

- Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50(2), 179–211. [https://doi.org/10.1016/0749-5978\(91\)90020-T](https://doi.org/10.1016/0749-5978(91)90020-T)
- Allen, J., Gregory, A., Mikami, A., Lun, J., Hamre, B., & Pianta, R. (2013). Observations of effective teacher-student interactions in secondary school classrooms: Predicting student achievement with the classroom assessment scoring system-secondary. *School Psychology Review*, 42(1), 76–98. <https://doi.org/10.1080/02796015.2013.12087492>
- Assor, A., Kaplan, H., & Roth, G. (2002). Choice is good, but relevance is excellent: Autonomy-enhancing and suppressing teacher behaviours predicting students' engagement in schoolwork. *British Journal of Educational Psychology*, 72(2), 261–278. <https://doi.org/10.1348/000709902158883>
- Collie, R. J., Griezera, H., & Martin, A. J. (2019). Teachers' motivational approach: Links with students' basic psychological need frustration, maladaptive engagement, and academic outcomes. *Teaching and Teacher Education*, 86, 1–13. <https://doi.org/10.1016/j.tate.2019.07.002>
- Connell, J. P., & Wellborn, J. G. (1991). Competence, autonomy, and relatedness: A motivational analysis of self-esteem processes. In M. R. Gunnar, & L. A. Sroufe (Eds.), *Vol. 23. Self-processes and development: The Minnesota symposia on child*

- development (pp. 44–77). Erlbaum.
- Den Brok, P., & Levy, J. (2005). Teacher-student relationships in multicultural classes: Reviewing the past, preparing the future. *International Journal of Educational Research*, 43(1–2), 72–88. <https://doi.org/10.1016/j.ijer.2006.03.007>
- Engels, M. C., Phalet, K., Gremmen, M. C., Dijkstra, J. K., & Verschuere, K. (2020). Adolescents' engagement trajectories in multicultural classrooms: The role of the classroom context. *Journal Of Applied Developmental Psychology*, 69, 1–14. <https://doi.org/10.1016/j.appdev.2020.101156>
- Finn, J. D. (1993). *School engagement and students at risk* (NCES-93-470). U.S. Department of Education, National Center for Education Statistics.
- Ghafarpour, H., & Moinsadeh, A. (2020). A dynamic systems analysis of classrooms: Teacher experience and student motivation. *Learning Environments Research*, 23, 101–116. <https://doi.org/10.1007/s10984-019-09293-y>
- Henry, K. L., Knight, K. E., & Thornberry, T. P. (2012). School disengagement as a predictor of dropout, delinquency, and problem substance use during adolescence and early adulthood. *Journal of Youth and Adolescence*, 41(2), 156–166. <https://doi.org/10.1007/s10964-011-9665-3>
- Henry, A., & Thorsen, C. (2021). Teachers' self-disclosures and influences on students' motivation: A relational perspective. *International Journal of Bilingual Education and Bilingualism*, 24(1), 1–15. <https://doi.org/10.1080/13670050.2018.1441261>
- Hollenstein, T. (2007). State space grids: Analyzing dynamics across development. *International Journal of Behavioral Development*, 31(4), 384–396. <https://doi.org/10.1177/0165025407077765>
- Hollenstein, T. (2013). *State space grids: Depicting dynamics across development*. Springer.
- Hollenstein, T., Granic, I., Stoolmiller, M., & Snyder, J. (2004). Rigidity in parent-child interactions and the development of externalizing and internalizing behavior in early childhood. *Journal of Abnormal Child Psychology*, 32(6), 595–607. <https://doi.org/10.1023/B:JACP.0000047209.37650.41>
- Hollenstein, T., & Lewis, M. D. (2006). A state space analysis of emotion and flexibility in parent-child interactions. *Emotion*, 6(4), 656–662. <https://doi.org/10.1037/1528-3542.6.4.656>
- Hornstra, L., Stroet, K., van Eijden, E., Goudsblom, J., & Roskamp, C. (2018). Teacher expectation effects on need-supportive teaching, student motivation, and engagement: A self-determination perspective. *Educational Research and Evaluation*, 24(3–5), 324–345. <https://doi.org/10.1080/13803611.2018.1550841>
- Jang, H., Reeve, J., & Deci, E. L. (2010). Engaging students in learning activities: Is it not autonomy support or structure but autonomy support and structure. *Journal of Educational Psychology*, 102(3), 588–600. <https://doi.org/10.1037/a0019682>
- Kajamies, A. (2017). *Towards optimal scaffolding of low achievers' learning: Combining intertwined, dynamic, and multi-domain perspectives* [Doctoral dissertation, University of Turku, Finland]. University of Turku repository. <https://www.utupub.fi/bitstream/handle/10024/133898/AnnalesB434Kajamies.pdf?sequence=2&isAllowed=y>
- Kupers, E., van Dijk, M., & van Geert, P. (2015). Within-teacher differences in one-to-one teacher–student interactions in instrumental music lessons. *Learning and Individual Differences*, 37, 283–289. <https://doi.org/10.1016/j.lindif.2014.11.012>
- Kupers, E., van Dijk, M., & van Geert, P. (2017). Changing patterns of scaffolding and autonomy during individual music lessons: A mixed methods approach. *The Journal of the Learning Sciences*, 26(1), 131–166. <https://doi.org/10.1080/10508406.2016.1259624>
- Kupers, E., van Dijk, M., van Geert, P., & McPherson, G. E. (2015). A mixed-methods approach to studying co-regulation of student autonomy through teacher–student interactions in music lessons. *Psychology of Music*, 43(3), 333–358. <https://doi.org/10.1177/0305735613503180>
- Lamey, A., Hollenstein, T., Lewis, M. D., & Granic, I. (2004). *GridWare* [Computer software]. State space grids version 1.1. <http://www.statespacegrids.org>
- Lavelli, M., Pantoja, A. P. F., Hsu, H., Messinger, 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). Blackwell Publishing Ltd. <https://doi.org/10.1002/9780470756676.ch3>
- Lei, H., Cui, Y., & Zhou, W. (2018). Relationships between student engagement and academic achievement: A meta-analysis. *Social Behavior and Personality*, 46(3), 517–528. <https://doi.org/10.2224/sbp.7054>
- Lewis, M. D., Lamey, A. V., & Douglas, L. (1999). A new dynamic systems method for the analysis of early socioemotional development. *Developmental Science*, 2(4), 457–475. <https://doi.org/10.1111/1467-7687.00090>
- 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. <https://doi.org/10.1016/j.learninstruc.2010.03.003>
- Mainhard, M. T., Pennings, J. J. M., Wubbels, T., & Brekelmans, M. (2012). Mapping control and affiliation in teacher-student interaction with State Space Grids. *Teaching and Teacher Education*, 28(7), 1027–1037. <https://doi.org/10.1016/j.tate.2012.04.008>
- Malmberg, L.-E., Hagger, H., Burn, K., Mutton, T., & Colls, H. (2010). Observed classroom quality during teacher education and two years of professional practice. *Journal of Educational Psychology*, 102(4), 916–932. <https://doi.org/10.1037/a0020920>
- McKellar, S. E., Cortina, K. S., & Ryan, A. M. (2020). Teaching practices and student engagement in early adolescence: A longitudinal study using the classroom assessment scoring system. *Teaching And Teacher Education*, 89, 1–11. <https://doi.org/10.1016/j.tate.2019.102936>
- Menninga, A., van Geert, P., van Vondel, S., Steenbeek, H., & van Dijk, M. (2021). Teacher-student interaction patterns change during an early science teaching intervention. *Research in Science Education*, 1–27. <https://doi.org/10.1007/s11165-021-09997-3>
- Minnaert, A., Kupers, E., de Boer, A., & de Jong, F. (2016). *Differentiation inside out: A study of differentiation on different levels and domains* [unpublished research proposal]. Nationaal Regieorgaan Onderwijsonderzoek (NRO).
- Olivier, E., Galand, B., Morin, A. J. S., & Hospel, V. (2021). Need-supportive teaching and student engagement in the classroom: Comparing the additive, synergistic, and global contributions. *Learning and Instruction*, 71, 1–18. <https://doi.org/10.1016/j.learninstruc.2020.101389>
- Otundo, J. O., & Garn, A. C. (2019). Student interest and engagement in middle school physical education: Examining the role of needs supportive teaching. *International Journal of Educational Psychology*, 8(2), 137–161. <https://doi.org/10.17583/ijep.2019.3356>
- Pelletier, L. G., Séguin-Lévesque, C., & Legault, L. (2002). Pressure from above and pressure from below as determinants of teachers' motivation and teaching behaviors. *Journal of Educational Psychology*, 94(1), 186–196. <https://doi.org/10.1037/0022-0663.94.1.186>
- 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., & Hollenstein, T. (2020). Teacher-student interactions and teacher interpersonal style: A state space grid analysis. *The Journal of Experimental Education*, 88(3), 382–406. <https://doi.org/10.1080/00220973.2019.1578724>
- Pennings, H. J. M., & Mainhard, T. (2016). Analyzing teacher-student interactions with state space grids. In M. Koopmans, & D. Stamovlasis (Eds.), *Complex dynamical systems in education: Concepts, methods and applications* (pp. 233–271). Springer. https://doi.org/10.1007/978-3-319-27577-2_12
- 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. <https://doi.org/10.1016/j.tate.2013.07.016>
- Pianta, R. C., & Hamre, B. K. (2009). Conceptualization, measurement, and improvement of classroom processes: Standardized observation can leverage capacity. *Educational Researcher*, 38(2), 109–119. <https://doi.org/10.3102/0013189X0932374>
- Pianta, R. C., Hamre, B. K., & Allen, J. P. (2012). Teacher-student relationships and engagement: Conceptualizing, measuring, and improving the capacity of classroom interactions. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 365–386). Springer. <https://doi.org/10.1007/978-1-4614-2018-7>
- Pietarinen, J., Soini, T., & Pyhältö, K. (2014). Students' emotional and cognitive engagement as the determinants of well-being and achievement in school. *International Journal of Educational Research*, 67, 40–51. <https://doi.org/10.1016/j.ijer.2014.05.001>
- Raphael, L. M., Pressley, M., & Mohan, L. (2008). Engaging instruction in middle school classrooms: An observational study of nine teachers. *The Elementary School Journal*, 109(1), 61–81. <https://doi.org/10.1086/592367>
- Reeve, J. (2012). A self-determination theory perspective on student engagement. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 149–172). Springer. https://doi.org/10.1007/978-1-4614-2018-7_7
- Reeve, J., Jang, H., Carrell, D., Jeon, S., & Barch, J. (2004). Enhancing students' engagement by increasing teachers' autonomy support. *Motivation and Emotion*, 28(2), 147–169. <https://doi.org/10.1023/B:MOEM.0000032312.95499.6f>
- Reeve, J., & Lee, W. (2014). Students' classroom engagement produces longitudinal changes in classroom motivation. *Journal of Educational Psychology*, 106(2), 527–540. <https://doi.org/10.1037/a0034934>
- Rimm-Kaufman, S. E., Baroody, A. E., Larsen, R. A., A., Curby, T. W., & Abry, T. (2015). To what extent do teacher-student interaction quality and student gender contribute to fifth graders' engagement in mathematics learning? *Journal of Educational Psychology*, 107(1), 170–185. <https://doi.org/10.1037/A0037252>
- Roorda, D. L., Koomen, H. M. Y., Spilt, J. L., & Oort, F. J. (2011). The influence of affective teacher-student relationships on students' school engagement and achievement: A meta-analytic approach. *Review of Educational Research*, 81(4), 493–529. <https://doi.org/10.3102/0034654311421793>
- Ruzek, E. A., Hafen, C. A., Allen, J. P., Gregory, A., Mikami, A. Y., & Pianta, R. C. (2016). How teacher emotional support motivates students: The mediating roles of perceived peer relatedness, autonomy support, and competence. *Learning and Instruction*, 42, 95–103. <https://doi.org/10.1016/j.learninstruc.2016.01.004>
- Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, 55(1), 68–78.
- Sheldon, K. M., & Niemiec, C. P. (2006). It's not just the amount that counts: Balanced need satisfaction also affects well-being. *Journal of Personality and Social Psychology*, 91(2), 331–341. <https://doi.org/10.1037/0022-3514.91.2.331>
- Sherin, M., & van Es, E. (2005). Using video to support teachers' ability to notice classroom interactions. *Journal of Technology and Teacher Education*, 13(3), 475–491.
- Skinner, E. A., & Belmont, M. J. (1993). Motivation in the classroom: Reciprocal effects of teacher behavior and student engagement across the school year. *Journal of Educational Psychology*, 85(4), 571–581. <https://doi.org/10.1037/0022-0663.85.4.571>
- 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(3), 493–525. <https://doi.org/10.1177/0013164408323233>
- Smith, L. B., & Thelen, E. (1993). *A dynamic systems approach to development: Applications*. The MIT Press.
- Snijders, T. A. B., & Bosker, R. J. (1999). *Multilevel analysis: An introduction to basic and advanced multilevel modeling*. SAGE Publications.
- Steenbeek, H., & van Geert, P. (2013). The emergence of learning-teaching trajectories in education: A complex dynamic systems approach. *Nonlinear Dynamics, Psychology, and Life Sciences*, 17(2), 233–267.
- Stroet, K. (2014). *Studying motivation in classrooms: Effects of teacher practices on early adolescents' motivation* [Doctoral dissertation, University of Groningen, The Netherlands]. University of Groningen Research Database. <http://hdl.handle.net/11370/6da2257e-77ed-49e2-a8ab-804549f830ae>.
- Stroet, K., Opdenakker, M.-C., & Minnaert, A. (2013). Effects of need supportive teaching on early adolescents' motivation and engagement: A review of the literature. *Educational Research Review*, 9, 65–87. <https://doi.org/10.1016/j.edurev.2012.11.003>
- Stroet, K., Opdenakker, M.-C., & Minnaert, A. (2015). What motivates early adolescents for school? A longitudinal analysis of associations between observed teaching and motivation. *Contemporary Educational Psychology*, 42, 129–140. <https://doi.org/10.1016/j.cedpsych.2015.06.002>
- Thelen, E., & Smith, L. (1994). *A dynamic systems approach to the development of cognition and action*. CogNet <http://cognet.mit.edu>.
- Tripp, T. R., & Rich, P. J. (2012). The influence of video analysis on the process of teacher change. *Teaching and Teacher Education*, 28(5), 728–739. <https://doi.org/10.1016/j.tate.2012.01.011>
- Turner, J. C., & Christensen, A. L. (2020). Using state space grids to analyze teacher-student interaction over time. *Educational Psychologist*, 55(4), 256–266. <https://doi.org/10.1080/00461520.2020.1793763>
- 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(6), 1195–1226. <https://doi.org/10.3102/0002831214532515>
- Van Braak, M., Van de Pol, J., Poorthuis, A. M. G., & Mainhard, T. (2021). A micro-perspective on students' behavioral engagement in the context of teachers' instructional support during seatwork: Sources of variability and the role of teacher adaptive support. *Contemporary Educational Psychology*, 64. <https://doi.org/10.1016/j.cedpsych.2020.101928>
- Van Dijk, M., & van Geert, P. (2015). The nature and meaning of intraindividual variability in development in the early life span. In M. Diehl, K. Hooker, & M. J. Sliwinski (Eds.), *Handbook of intraindividual variability across the life span* (pp. 37–58). Taylor and Francis.
- Van Vondel, S., Steenbeek, H., van Dijk, M., & van Geert, P. (2017). Ask, don't tell: A complex dynamic systems approach to improving science education by focusing on the co-construction of scientific understanding. *Teaching and Teacher Education*, 63, 243–253. <https://doi.org/10.1016/j.tate.2016.12.012>
- Van den Berghe, L., Cardon, G., Tallir, I., Kirk, D., & Haerens, L. (2016). Dynamics of need-supportive and need-thwarting teaching behavior: The bidirectional relationship with student engagement and disengagement in the beginning of a lesson. *Physical Education and Sport Pedagogy*, 21(6), 653–670. <https://doi.org/10.1080/17408989.2015.1115008>
- Van den Berghe, L., Tallir, I. B., Cardon, G., Aelterman, N., & Haerens, L. (2015). Student (dis)engagement and need-supportive teaching behavior: A multi-informant and multilevel approach. *Journal of Sport & Exercise Psychology*, 37(4), 353–366. <https://doi.org/10.1123/jsep.2014-0150>
- Van de Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in teacher-student interaction: A decade of research. *Educational Psychology Review*, 22(3), 271–296. <https://doi.org/10.1007/s10648-010-9127-6>
- 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). Routledge.
- Virtanen, T. E., Vaaland, G. S., & Ertesvåg, S. K. (2019). Associations between observed patterns of classroom interactions and teacher wellbeing in lower secondary school. *Teaching And Teacher Education*, 77, 240–252. <https://doi.org/10.1016/j.tate.2018.10.013>
- Wang, M.-T., Chow, A., Hofkens, T., & Salmela-Aro, K. (2015). The trajectories of student emotional engagement and school burnout with academic and psychological development: Findings from Finnish adolescents. *Learning and Instruction*, 36, 57–65. <https://doi.org/10.1016/j.learninstruc.2014.11.004>
- Wang, M.-T., & Eccles, J. S. (2011). Adolescent behavioral, emotional, and cognitive engagement trajectories in school and their differential relations to educational success. *Journal of Research on Adolescence*, 22(1), 31–39. <https://doi.org/10.1111/j.1532-7795.2011.00753.x>
- Wang, M.-T., & Fredricks, J. A. (2014). The reciprocal links between school engagement, youth problem behaviors, and school dropout during adolescence. *Child Development*, 85(2), 722–737. <https://doi.org/10.1111/cdev.12138>
- Wubbels, T., Brekelmans, M., den Brok, P., & van Tartwijk, J. (2011). 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). Routledge.
- Wubbels, T., den Brok, P., Veldman, I., & van Tartwijk, J. (2006). Teacher interpersonal competence for Dutch secondary multicultural classrooms. *Teachers and Teaching: Theory and Practice*, 12(4), 407–433. <https://doi.org/10.1080/13450600600644269>
- Zhen, R., Liu, R.-D., Ding, Y., Liu, Y., Wang, J., & Xu, L. (2018). The moderating role of intrinsic value in the relation between psychological needs support and academic engagement in mathematics among Chinese adolescent students. *International Journal of Psychology*, 53(4), 313–320. <https://doi.org/10.1002/ijop.12374>