Chapter 6

The dance of syntactic complexity

A CRQA analysis on co-adaptation processes of syntactic complexity in real-time teacher-student interactions during an intervention in kindergarten science lessons.

This chapter is submitted as:
6.1 Introduction

The bidirectional properties of language learning have been demonstrated in several studies (e.g. Bronfenbrenner & Morris, 2006; Sameroff & MacKenzie, 2003; Van Dijk & Van Geert, 2011; Van Dijk et al., 2013; Van Geert, Steenbeek, & Van Dijk, 2011). Also, many researchers agree on the importance of social interaction for language development (Dickinson & Porsche, 2011; Powell, Diamond, Burchinal & Koehler, 2010). In classrooms settings, the teacher-student interaction provides a unique entry point for educational interventions in that improving this interaction can be the direct focus of the intervention (Barber & Mourshed, 2007) or that the interaction may be regarded as a contributing factor to succesfull implementation of an intervention. The intervention that is described in this paper aimed at improving the quality of the teacher-student interaction and used micro coding of these real-time observations to evaluate the effectiveness. Therefore, it is important to use novel analysis techniques that allow capturing the complexity of language use in interaction. Traditional evaluation analyses – such as RCT – are often used to study whether an intervention works, but these analyses do not provide information about how and when change occurs at the micro level. In order to gain insight into possible changes in the dynamics of the teacher-student interaction innovative techniques are required. One of the main reasons why change processes associated with interventions were not widely studied was the lack of appropriate methodological tools to study them effectively (Granic & Hollenstein, 2003). Recently, more studies have focused on processes of change while taking into account inter- and intra-individual variability (Granic, O’Hara, Pepler, & Lewis, 2007; Lichtwarck-Aschoff, Hasselman, Cox, Pepler, & Granic, 2012; Turner, Christensen, Kackar-Cam, Trucano & Fulmer, 2014; Van Vondel, Steenbeek, Van Dijk, & Van Geert, 2016). In part, these studies investigate profiles and pathways of change in the structure of adult-child interactions by quantifying the dynamics within these interactions. The aim of the current paper is to examine the dynamics of language use in real-time teacher-student interactions and to analyze whether this dynamics changes in the course of an intervention called “Language as a Tool for learning science” (LaT). This intervention is professionalization training for teachers based on video feedback coaching. The LaT aims to improve the quality of kindergarten science lessons with a specific focus on language interaction since science education both demands and supports complex language (Glass & Oliveira, 2014; Wellington & Osborne, 2001). In this paper, we investigate the dynamics of teacher-student interaction – which is measured by sentences of the same syntactic category – and possible changes therein over the intervention period.

6.1.1 Complex dynamic systems approach

Today, studying patterns within micro-level real-time interactions in educational settings is proposed by the complex dynamic systems approach (Kunnen & Van Geert, 2012; Steenbeek & Van Geert, 2013; Van Geert, 1994; 2003; Van Geert & Verspoor, 2015). Language can be seen as the product of a continuously changing process between and within interacting and adapting
complex dynamic systems (in this case: teacher and students), which can best be characterized by its iterative and nonlinear nature (Cameron & Larsen-Freeman, 2007; Van Geert, 2003; Van Geert & Verspoor, 2015). Highly coordinated language interactions are related to more optimal developmental outcomes. However, the existence of inter- and intra-individual variability is inherent to these processes as interaction is transactional in nature. The amount of variability is related to stability and flexibility in the teacher-student interaction and provides information about the coupling dynamics within the teacher-student interaction as a system. Low variability in patterns of language use indicates that an interaction is organized, and a lack of variability can indicate rigidity. Large variability indicates a high degree of context dependency and exploration, which means that the speakers are more flexibly coupled (Van Dijk & Van Geert, 2015).

6.1.2 Coordination of syntactic complexity
Language is of great importance in (early) science lessons (Snow, 2014; Wellington & Osborne, 2001). The acquisition of sophisticated forms of language use, including increasing syntactic complexity, is required to appropriately ‘speak science’ (Gee & Green, 1998). This is a process of co-constructing complex science discourse, which entails coordination between teacher and students in a way that enables students to sufficiently understand and contribute to the conversation (Clark, 1996; Garrod & Pickering, 2004; Mercer, 1995). To achieve this contribution, they align their words, grammar and sounds in order to ultimately create mutual understanding (Brown-Schmidt & Tanenhaus, 2008; Pickering & Garrot, 2004).

Many studies have emphasized the crucial role of adaptive processes in language development of children (e.g. Snow, 1972; Van Dijk et al., 2013). Language can be seen as an ordered, coupled and meaningful sequence of utterances of the individual in a specific interactional context (e.g. teacher-student discourse during science lesson). Typically, the utterances of the interaction partners are not independent, but are co-constructed and coordinated, to create meaning and understanding. Both teacher and students (co-)adapt their individual utterances to the other, and the probability that certain combinations of utterances will recur within and across multiple interactions increases, creating more predictable patterns of language use. From previous studies, we know that speakers coordinate their language use on various levels; for instance on vocalisations (Goldstein, King, & West, 2003), speech characteristics (Ko, Seidl, Cristia, Reimchen, & Soderstrom, 2015; Reuzel, Embregts, Bosman, Cox, Van Nieuwenhuijzen, & Jahoda, 2013; Reuzel, Embregts, Bosman, Cox, Van Nieuwenhuijzen, & Jahoda, 2014), verbal expressions (Brennan & Clark, 1996; Garrod & Anderson, 1987; TamisLeMonda & Bornstein, 2002), syntactic complexity (Branigan, Pickering, & Cleland, 2000; Dale & Spivey, 2006; Hopkins, Yuill, & Keller, 2016; Van Dijk et al., 2013) but also in gestures, gazes and body posture during conversation (Abney, Warlaumont, Haussman, Ross & Wallot, 2014; De Jonge-Hoekstra, Van der Steen, Van Geert, & Cox, 2016; Golden-Meadow, 1998; Richardson, Dale & Kirkham, 2007; Shockley, Baker, Richardson, Fowler, 2007). Coordination of syntactic complexity in the teacher-student interaction is the focus of the
current study. In this paper, coordination is defined as the on-going and (un)intentional process of mutual interpersonal adaptation (Garrod & Pickering, 2009; Van Dijk, Cox, & Van Geert, 2016). This means that within an on-going interaction, input as well as (effective) contingent responses of both teachers and students shape their language toward *syntactic coordination* (Dale & Spivey, 2006): teacher and students are inclined to produce utterances that correspond – regarding syntactic complexity – to those being heard. This process of mutual dependency among relatively independent components derived from two (sub)systems is often referred to as *coupling*.

Both experimental and observational studies provide support that individuals coordinate their syntactic structure while interacting (Branigan et al., 2000; Cox & Van Dijk, 2013; Dale & Spivey, 2006; Sokolov, 1993). In one of our previous studies, we confirmed the existence of transactional relations – which are the mutual influences in interaction, also known as bidirectional relations – regarding syntactic complexity in the context of naturalistic kindergarten science lessons (see Chapter 3). To be more specific, we found that syntactically complex utterances of one speaker were related to complex utterances of the other speaker, pointing towards a bidirectional dependency. The tendency of teachers to imitate the level of complexity of their students’ language in immediately consecutive utterances was strongest compared to students imitating the teachers’ level of syntactic complexity. This is in contrast with the findings of Dale and Spivey (2006) which showed that older children were more often leaders, whereas the younger children were more guided by adults – in terms of timing – within the process of syntactic coordination. The contribution of the present paper is that we investigate syntactic coordination, which is defined as using sentences of the same syntactic category (no sentence, simple sentence, complex sentence), over multiple utterances within one session and across the course of an intervention. In addition, we aim to get insights into the relative strength and the direction of this coordination process. The relative strength can be interpreted as the symmetry in the dynamics between syntactic complexity of the teacher and syntactic complexity of the students within an interaction. The direction reflects the extent to which syntactic structures of teachers influence – or lead in time – syntactic structures of students, and vice versa.

### 6.1.3 The intervention

This paper is based on video observations from the intervention ‘Language as Tool’ (LaT), which was implemented as a professionalization training for kindergarten teachers in science lessons. The intervention is based on the assumption that kindergarten science lessons provide excellent opportunities to integrate content learning and language learning (Conezio & French, 2002; French, 2004; French & Peterson, 2009; Samarapungavan, Mantzicopoulos, Patrick & French, 2008). In order to successfully participate in science lessons, students are expected to advance in language and at the same time, science lessons offer opportunities for students to acquire and practice sophisticated language skills. The acquisition of sophisticated language skills is considered a great challenge because children need to express complex thoughts with...
limited language skills (Snow & Uccelli, 2009). The goal of the intervention was to improve the quality of teachers’ science teaching in kindergarten. The intervention was based on video feedback coaching for teachers, which means that teachers received personal coaching based on principles of (school) video interaction guidance (Kennedy, Landor & Todd, 2011; Van den Heijkant et al., 2006). The professional training combined several components which are important in early science education, and which will be introduced briefly (for an extensive description of the intervention see Chapter 4).

First, the empirical cycle is introduced as an effective means to structure the thinking process of students during science lessons (De Groot, 1994; Dejonckheere, Van De Keere & Mestdagh, 2009; Gelman & Brenneman, 2004). This means making continuous use of a research method of asking research questions, predicting, testing, observing and analyzing, and drawing conclusions. The empirical cycle lends itself perfectly for teachers to facilitate the learning process by encouraging students to verbalize ideas by asking open questions (Chin, 2006; Lee & Kinzie, 2012; Oliveira, 2010).

The second component that is introduced to teachers is how and when to make effective use of open-ended questioning strategies. Open-ended questions are found to be most effective for stimulating children to talk (Oliveira, 2010) and for language development (De Rivera, Giralometto, Greenberg & Weitzman, 2005; Dickinson, 2001; Mashburn et al., 2008; Peisner-Feinberg et al., 2001). Open-ended questions provide opportunities for more linguistically and cognitively challenging discourse (De Rivera et al., 2005; Massey, Pence, Justice & Bowles, 2008; Wasik & Bond, 2001; Wasik, Bond, & Hindman, 2006).

The third – and maybe most important – component of this intervention is to make teachers aware of the important role of complex, sophisticated, and explicit language use during early science education by providing them with information and strategies on modelling and evoking sophisticated language from students. Language is essential to learning science and science lessons provide multiple language learning opportunities (Snow, 2014; Wellington & Osborne, 2001). Engagement in these lessons, in particular in kindergarten, both demands and supports sophisticated science discourse, which brings along sophisticated forms of language use, such as domain-specific vocabulary, dense presentation of information, and complex sentences structures (Schleppegrell, 2001). As the acquisition and advancement of sophisticated forms of language is considered a great challenge, it is important that children are introduced to this register from a young age onwards (Snow, 2010; Snow & Uccelli, 2009; Schleppegrell, 2004) and therefore, kindergarten science education can provide a context for the development of sophisticated language. Important teacher talk predictors to improve students’ sophisticated language skills are cognitive and linguistic stimulation, the use of diverse vocabulary and syntactic complexity (Dickinson, 2001; Snow, 2014). Science lessons thus provide an appropriate context for students to become (more) proficient in using complex syntax to express complex ideas. In order to verbalize complex thoughts, exposure is required to various ways in which sentences can be connected through combining clauses and through the use of conjunctions to express particular relations between clauses.
In sum, we expect that – as a result of the intervention – the teacher-student interaction will change from a more teacher-led interaction to a more adaptive interaction. By adaptive, we mean that teachers are more sensitive to the abilities, needs and opportunities of students, and that by carefully listening to the students – what they say and particularly how they say it – the teachers are expected to be better able to evoke more and complex language from their students. In the current paper, the focus is on adaptation processes regarding syntactic complexity.

### 6.1.4 Recurrence

The complex dynamic systems approach offers several methods to investigate the syntactic coordination within real-time teacher-student interactions. Particularly, the cross-recurrence quantification analysis (CRQA) (Marwan, Romano, Thiel & Kurths, 2007; Webber & Zbilut, 2005), is a technique used to quantify the interactions. This technique allows us in particular to study the coupling and attunement within this system of language-producing teacher and students. This powerful technique has been applied to studies on language and development to reveal structural and temporal patterns in naturalistic settings (Cox & Van Dijk, 2013; Dale & Spivey, 2006; De Graag, Cox, Hasselman, Jansen, & De Weerth, 2012; De Jonge-Hoekstra et al., 2016; Lichtwarck-Aschoff et al., 2012; Reuzel et al., 2013; 2014). Recently, additional analyses have been introduced for CRQA on categorical units of measure (e.g. words, sentences structures), which are often encountered in studying development (Cox, Van der Steen, Guevara-Geurrero, De Jonge-Hoekstra, & Van Dijk, 2016). CRQA draws on quantitative measures for the extent to which teachers’ and students’ language use match (in a particular way, as will be elaborated on below) across a dialog, also referred to as cross-recurrences. In contrast to more traditional techniques, including lag-sequential analysis (Dale, Warlaumont & Richardson, 2011), CRQA is not restricted to such cross-recurrences at the same time, or within some fixed time window before or after an event, but it quantifies recurrent patterns across all possible timescales, and, therefore, includes in its analysis matches of all utterances across the entire interaction. In other words, this method aims to quantify the coordination and reveals global structures and temporal patterns of language within real-time teacher-student interactions, and whether these patterns move toward syntactic coordination.

### 6.1.5 The current study

The goal of this paper is to, quantify the relative strength and direction of coordination between teacher and students regarding syntactic complexity, and investigate whether this coordination process changes during an intervention in early science lessons, by applying the CRQA technique.

**Research question 1.**

The first research question addresses the global effectiveness of the intervention measured by counting frequencies: *Does the use of syntactic categories (no sentence, simple sentence,*
complex sentence) change in the course of the intervention? The intervention is aimed at raising awareness of the importance of complex language during science lessons, and provides teachers with information and tools how to stimulate complex language in students (as will be explained in the method section). Over the eight lessons, changes in the use of the different categories are expected for both teachers and students toward more syntactically complex sentence structures. This would be reflected by more complex sentences and less simple and no-clause sentences. A general description of these results provides context to the subsequent CRQA.

Research question 2.
The second research question is: What is the relative strength and direction of syntactic coordination between teachers and students, and how does this change in the course of the intervention? (2a). Studies thus far have demonstrated that speakers coordinate the complexity of their language use in interaction (Branigan, Pickering & Cleland, 2000; Dale & Spivey, 2006; Van Dijk et al., 2013; Tamis-LeMonda & Bornstein, 2002). This study aims to explore to what degree syntactic structures used by teachers and students during science lessons are coupled, and whether this process of syntactic coordination changes across the course of an intervention aimed at changing language use.

As a next step, we investigated the coupled dynamics within the different syntactic categories in order to answer research question 2b: What is the relative strength of syntactic coordination for the different syntactic categories, and how does this change in the course of the intervention? We expected to detect different changes over time for the respective categories, because the intervention is partly aimed at increasing the use of more complex sentence structures, which might result in stronger and more stable coupling of teachers’ and students’ use of complex sentences later.

6.2 Method
6.2.1 Participants
Seven (female) teachers with a small group of students (three to six students per teacher) participated voluntarily in this study. In this study we will refer to them as A, B, C, D, E, F, and G. At the start of the data collection, the teachers were between 30 and 60 years old ($M = 44$, $SD = 13$). On average, teachers had 17 years of teaching experience (range = 7-33, $SD = 10$) and very limited experience in teaching science. The participating students ($N = 34$) were four and five years of age, and were more or less evenly distributed according to gender (56% boys/44% girls). All teachers and students were native speakers of the Dutch language. According to the teachers, none of the participating students had any notable developmental problems.
6.2.2 Material and measures

Transcription procedure.

The central part (middle five minutes) of the video recorded lessons were transcribed following the Codes for Human Analysis of Transcripts (CHAT) conventions (MacWhinney, 2000) by the author of this dissertation and a trained assistant-researcher. The unit of transcription was the utterance. Utterance boundaries were determined based on turn taking, pauses and on intonation patterns (Brown, 1973). Partly and completely unintelligible utterances were excluded from analysis and only task-related utterances were included in the analysis. All students together were considered ‘the speaking partner’ of the teacher during the small group science activities, and therefore a speaker was marked either as ‘teacher’ or ‘students’ in the transcript.

Coding syntactic complexity.

The coding scheme – with mutually exclusive and exhaustive categories – was based on the description of syntactic complexity provided in Huttenlocher et al. (2002). We coded each utterance for sentence complexity using the following codes: (0) the utterance contained no clause, (1) the utterance contained one clause (simple sentence), or (2) the utterance contained multiple clauses (complex sentence). This coding procedure is illustrated with a transcript – reflecting a discussion on the floating and sinking of a mandarin with and without its skin – in which the utterances and corresponding codes are presented (see table 1).

Table 1
Transcript to illustrate coding of syntactic complexity.

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Dutch</th>
<th>English translation (literally)</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher</td>
<td>Hebben jullie een idee hoe het komt?</td>
<td>Do you have any idea how this works?</td>
<td>2</td>
</tr>
<tr>
<td>Student</td>
<td>Ja.</td>
<td>Yes.</td>
<td>0</td>
</tr>
<tr>
<td>Teacher</td>
<td>Jij zei dat het door het schilletje kwam, he?</td>
<td>You said that is because of the skins (of the mandarin).</td>
<td>2</td>
</tr>
<tr>
<td>Student</td>
<td>Ja kijk, het schilletje zorgt voor heel veel energie.</td>
<td>Yes look, the skin causes a lot of energy.</td>
<td>1</td>
</tr>
<tr>
<td>Teacher</td>
<td>Het schilletje zorgt voor energie...</td>
<td>The skin causes energy...</td>
<td>1</td>
</tr>
<tr>
<td>Teacher</td>
<td>Hoe bedoel je dat?</td>
<td>What is energy?</td>
<td>1</td>
</tr>
<tr>
<td>Student</td>
<td>Wat is energie?</td>
<td>That makes you light.</td>
<td>1</td>
</tr>
<tr>
<td>Teacher</td>
<td>Daar word je licht door.</td>
<td>You mean that it makes you light?</td>
<td>1</td>
</tr>
<tr>
<td>Student</td>
<td>Je bedoelt dat je daar licht door wordt?</td>
<td>Yes.</td>
<td>2</td>
</tr>
<tr>
<td>Student</td>
<td>Ja.</td>
<td>And without a skin it becomes heavier, because there is a whole in and than the air goes out.</td>
<td>2</td>
</tr>
<tr>
<td>Teacher</td>
<td>En zonder schilletje wordt ‘ie De hele tijd zwaarder, omdat er een gat in zit en dan gaat De lucht eruit.</td>
<td>O, you are already talking about air now.</td>
<td>2</td>
</tr>
<tr>
<td>Teacher</td>
<td>O. je hebt het ook al over lucht.</td>
<td>Adam, do you have any idea how this works?</td>
<td>1</td>
</tr>
<tr>
<td>Student</td>
<td>Adam, heb jij een idee hoe het zit?</td>
<td>Yes, because it is round and because the skin is off and that it becomes lighter.</td>
<td>2</td>
</tr>
<tr>
<td>Teacher</td>
<td>Ja omdat het rond is en omdat het schilletje eraf is en dat ie dan lichter gaat worden.</td>
<td>Ok, all right.</td>
<td>0</td>
</tr>
</tbody>
</table>

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**Reliability.**

The inter-rater reliability for the application of the coding scheme was computed over 20% of the transcripts. Both the inter-observer agreement (88%) and the inter-rater reliability based on Cohen's Kappa ($K = .83$) were almost perfect (Landis & Koch, 1977).

### 6.2.3 Procedure

The data were systematically collected (video recorded) in naturalistic classroom situations during science lessons. Teachers were instructed to select three to six students, varying in age, gender and cognitive level. Teachers were recruited from schools in a regional collaboration project about science education but had limited experience with actual teaching science. Teachers and parents of the participating students gave informed consent before the start of the study with these procedures being approved by the local Ethical Committee Psychology of the University of Groningen.

Participating teachers were instructed to give a science lesson on a subject of their own choice (15-20 minutes). Students were not specifically informed beforehand. After the first two lessons (pre-measurements), all teachers in the intervention group attended an information meeting about the general principles of teaching science as formulated in the Curious Minds program. Teachers were informed about questioning strategies, the empirical cycle and sophisticated language during science education. This information was illustrated by means of video clips from the teachers’ own science lessons (pre-measurements) (Seidel, Stürmer, Blomberg, Kobarg, & Schwindt, 2011). After this meeting, teachers specified a personal learning goal that was used as a special point of interest for both teacher and coach in the coaching sessions. This personal learning goal was aimed at stimulating the intrinsic motivation of the teachers and had to be in line with the coaching principles. Examples of teachers’ personal learning goals were: “I want to learn how to ask questions based on the empirical cycle” or “I want to learn to be explicit and avoid terms like ‘this’ and ‘there’.”

In the intervention stage (lesson 3-6), lessons were immediately followed by a coaching session particularly focused on the personal learning goal, the use of the empirical cycle, questioning skills and complex, sophisticated and explicit language use. Coaching was based on the principles of video feedback coaching (Strathie, Strathie & Kennedy, 2011; Van den Heijkant et al., 2006). The coach selected several moments from the lesson, based on a ratio of three moments that showed successful teacher behavior to one moment that indicated an area for development as a higher positivity ratio is needed for successful behavioral change to occur (Fredrickson, 2013). Coach and teacher discussed and reflected upon these moments to bring the teacher’s behavior to a conscious level (Van den Heijkant et al., 2006). The teacher was

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17 The basic principles of Curious Minds are that everyone is talented, adults should learn to recognize and stimulate the natural curiosity of children, adults should become talent-experts, adults are the motor behind further development of children’s talent and the best way to achieve this is case-based learning for adults.
provided with tools to enhance her skills in the following sessions. An experienced coach (author of this dissertation) performed the intervention using an extensive manual and, at the same time, adapted the coaching to the authentic teaching situations.

The (video) data collection of the intervention group consisted of two pre-intervention lessons, four lessons that were used for coaching purposes, and two post-intervention lessons. This resulted in eight measurements in total. Data were collected over three to four months, with sessions every one or two weeks. Post-measurements were collected two to four weeks after the last coaching session.

6.2.4 Analysis

**Proportions complex sentences.**

In order to answer research question 1, the average proportion of complex sentences was calculated for the teachers and students on all eight measurements. This proportion was calculated as the number of complex sentences (code 2) relative to all utterances. In the results section, the minimum and maximum values – which are the lowest and the highest proportion complex sentences per measurement – are also provided (min-max range).

**Data preparation.**

The video recordings were coded on utterance level, resulting in two event series of consecutive utterances per lesson, one for the teacher and one for the students. Table 2 provides an overview of the event series per teacher-student interaction.

<table>
<thead>
<tr>
<th>Teacher-student dyad</th>
<th>Average length</th>
<th>Minimum length</th>
<th>Maximum length</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>129</td>
<td>112</td>
<td>143</td>
</tr>
<tr>
<td>B</td>
<td>106</td>
<td>84</td>
<td>140</td>
</tr>
<tr>
<td>C</td>
<td>111</td>
<td>68</td>
<td>140</td>
</tr>
<tr>
<td>D</td>
<td>133</td>
<td>114</td>
<td>148</td>
</tr>
<tr>
<td>E</td>
<td>113</td>
<td>90</td>
<td>156</td>
</tr>
<tr>
<td>F</td>
<td>132</td>
<td>119</td>
<td>154</td>
</tr>
<tr>
<td>G</td>
<td>132</td>
<td>105</td>
<td>147</td>
</tr>
<tr>
<td>average</td>
<td>122</td>
<td>68</td>
<td>156</td>
</tr>
</tbody>
</table>

**Cross-Recurrence Quantification Analysis.**

The event series were analyzed by means of cross-recurrence quantification analysis (CRQA) to reveal structural and temporal patterns of syntactic coordination between teachers and students. The application of this innovative technique to categorical data is explained in more detail in previous papers (Cox et al., 2016; De Jonge-Hoekstra et al., 2016). The first step was to define recurrence, that is, the matching behaviors in the event series of teacher and students that form the basic unit of CRQA, and which appear as colored points in the CRP. In the current study, matching behavior was simply defined as teacher and students using the same syntactic category. This implicates that syntactic coordination is based on recurrences where an utterance of a certain syntactic category is matched by a preceding or following utterance of the same syntactic category utterance between the interaction partners. Because of the turn-taking
structure in regular dialog, the present study obviously does not contain exact equal time language-use matches. This means that the smallest unit (i.e. time scale) of analysis exists of a language-use match between two consecutive utterances. The CRQA procedure included all matching behaviors together (i.e., no sentence-no sentence, simple sentence-simple sentence and complex sentence-complex sentence) for Research Question 2a, and analyzed them separately for Research Question 2b. The CRQA was performed using special-purpose Matlab code.

Secondly, all matching values within a pair of event series were plotted in a cross-recurrence plot (CRP, see figure 1), by putting the event series of one speaker along the horizontal axis and that of the other speaker along the vertical axis. When using categorical data most dots in the CRP align to form (vertical and horizontal) rectangular structures. The occurrence of ‘rectangularity’ in the CRP and the extent of its anisotropy (i.e. direction dependence or dissimilarity along the two axes of the plot) reflect some persistence and asymmetry in the interaction, respectively. These structures indicate instances where a behavior expressed (briefly for a line, and longer for a block) by one subsystem (teacher or students), is accompanied by episodes of lingering in the matching behavior by the other subsystem (teacher or students). From this cross recurrence plot, several recurrence measures can be derived, which reveal the underlying temporal structure in the shared dynamics of the two interacting subsystems (teachers and students). This provides information about the shared dynamics of syntactic complexity in the teacher-student interaction, and specifically about the strength and direction of the coupling between the two subsystems (see Cox et al., 2016). The direction of the coordination is considered such that vertical line structures reflect the extent to which syntactic structures of teachers influence—or lead in time—syntactic structures of students, whereas horizontal line structures reflect the extent to which students syntactic structures influence syntactic structures of teachers.

![Figure 1](image1.png)

**Figure 1** A CRP produced by the cross-matching procedure, forming the basis for CRQA. In this case matches of categories of syntactic complexity were depicted by black line (and block) structures, together with the non-matching white areas.
Then, from the CRP, the measures laminarity (LAM), trapping time (TT) and maximum line (MaxL) were calculated along its two main axes. Laminarity indicates the proportion of recurrent points that comprise vertical rectangular structures (LAM_V) and horizontal rectangular structures (LAM_H), and reflect the degree to which each subsystem is ‘trapped’ into expressing matching syntactic categories for all consecutive periods of at least two utterances. Trapping time reflects the average time that one of the subsystems remains in a matching state triggered by the other. In this context, it is the average number of consecutive utterances that either teacher or students produce at the same level of syntactic complexity as the other produced at some point. TT measures are an indication of interactional rigidity (or flexibility). The length of the maximum (horizontal or vertical) line or block structure informs about the longest of such episodes, with MaxL_V reflecting the longest consecutive pattern of same syntactic complexity utterances by the teacher, and MaxL_H reflecting the longest pattern of the students. Following De Graag et al. (2012), a decline in these measures reflects an increase in the flexibility of (coupled) use of the three categories of sentences.

To capture the coupled dynamics of teacher’s and students’ language use, and reveal the extent of its asymmetry with regard to strength and direction, both vertical and horizontal line structures were quantified separately, in terms of non-diagonal line measures, and were compared (as will be explained below). As said before, the orientation of the rectangular structures (i.e. vertical and horizontal) provides differential and complementary information about the coupling between the two subsystems. In order to detect potential asymmetries in the coupling, the anisotropy of the CRP has to be quantified properly, for which we used the relative differences between the vertical and horizontal line measures (i.e. \((X_V - X_H) / (X_V + X_H)\)), following Cox et al. (2016).

In order to answer Research Question 2b, chromatic CRQA was performed. This method analyzes several kinds of behavioral matches – in this case matches of the level of syntactic complexity – separately, by tracking them with a color-coding. A straightforward way to implement this is by constructing a cross-recurrence plot, CRP(color), for each kind of behavioral match (color). By merging the separate CRP(color), all recurrences of the different kinds of behavioral matching can be represented by differently colored dots in a single, multi-colored CRP (see figure 2). Using chromatic (i.e. matching-type specific) CRQA, three colored cross-recurrence plots (CRP(color)) were analyzed and compared for each teacher-student interaction over the eight measurements. An example of a chromatic CRP is provided in figure 2. The first, CRP(green), only displays matches of the syntactic category no sentence, while the second, CRP(red), only displays matches of simple sentences, and the third, CRP(blue), displays matches of complex sentences. In this way, the recurrence rate of each CRP(color), as a basic measure of the coupling between teacher and students, informs about the coordination at a specific syntactic level. The simplest measure in chromatic CRQA is the recurrence rate of a color (RR(color)), quantifying the density of one kind of behavioral match (color) in this multi-color CRP. This means that the RR(color) depicts the proportion of recurrent points – the use of a specific syntactic category by teacher or students, matched by the use of that same syntactic
category by the other – across the entire CRP. RR, as a basic measure of the coupling between two subsystems, informs us about the syntactic coordination between teacher and students.

**Figure 2** A multi-colored checkerboard CRP produced by the cross-matching procedure, forming the basis for Chromatic CRQA. Three different matches of categories of syntactic complexity were distinguished, depicted by a green (no sentence), red (simple sentence) and blue (complex sentence) color code, together with the non-matching white areas. For further details about calculations on the CRP, see text.

**Slopes.**  
For both the proportions of complex sentences and for each variable resulting from the CRQA, we tested whether the measures showed an increase or decrease over the eight lessons. We used a non-parametric procedure, called Monte Carlo analysis (Good, 2006), where the linear slope of the empirical CRQA measures (LAM, MaxL, TT) was tested against the slope of randomly shuffled data. First, the slope was calculated over the empirical data, based on an average of all teachers. Second, the columns and rows with empirical data of all teachers are randomly shuffled, after which the slope was calculated again over the shuffled data. This procedure was repeated 10,000 times per test and results in a p value which indicates the probability that the slope of the empirical data stemmed from the distribution of slopes of shuffled data. The Monte Carlo analyses were performed in Microsoft Excel in combination with Poptools (version 3.2). As significance scores are not directly linked to practical significance (Sullivan & Feinn, 2012), the effect size was calculated using Cohen’s d. Based on Cohen’s classification (1992), effect sizes of .20, .50 and .80 (and the negative counterparts of -.20, -.50 and -.80) are small, medium and large, respectively. In order to determine whether the empirical data provided convincing, weak or no support for our hypotheses, we evaluated combinations of p values and d values. Only when the empirically-found value had a very small probability of being produced under the null-hypothesis – with a p value smaller than .05 and an effect size greater than .50 or -.50 – was it understood as convincing evidence supporting that the

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18 To download Poptools: http://www.poptools.org/download
empirical value was meaningful. Empirical results with a $p$ value between .05 and .10 and an effect size greater than .50 or -.50 can be understood as less convincing evidence, providing weak support. Results with relatively small effect sizes (below .50 or above -.50) – whatever the $p$ value – or with $p$ values above .10 – whatever the effect size – were understood as unconvincing evidence or no support.

### 6.3 Results

#### 6.3.1 Changes in use of syntactic categories

The first research question addressed whether there are global changes in the use of syntactic categories (no sentence, simple sentence, complex sentence) by both teachers and students separately in the course of the intervention. Figure 3 and 4 present the use of the different categories over the eight science lessons expressed by the teachers and the students. The teachers’ use of the category ‘no sentence’ slightly increased over time ($slope = .01, p = .10, d = 1.77$) providing weak support for a meaningful increase. Teachers started expressing convincingly fewer simple sentences over time ($slope = -.01, p = .03, d = -1.83$) and convincingly more complex sentences ($slope = .01, p = .03, d = 1.31$). For the students, use of the category ‘no sentence’ varied between measurements and the slope showed no support for changes over time ($slope = .01, p = .14, d = -.09$). The use of simple sentences convincingly decreased over time ($slope = -.02, p = .05, d = -.86$) and the use of complex sentences increased convincingly ($slope = .01, p < .01, d = 2.34$). In the course of the intervention, both teachers and students tended to use more syntactically complex sentence structures. It is remarkable that we see a pronounced decrease in the proportion simple sentences, which is most evident in the students (figure 4), at lesson 4. Despite these general trends, the wide ranges – in particular in case of the students – indicate interindividual variability.
Figure 3 Teachers’ use of syntactic categories (proportions of no sentence, simple sentence, complex sentence) over eight science lessons.
Figure 4 Students’ use of syntactic categories (proportions of no sentence, simple sentence, complex sentence) over eight science lessons.

6.3.2 Relative strength and direction of syntactic coordination
An overview of the measures resulting from the CRQA is presented in figures 5, 6 and 7. LAM$_V$ convincingly decreased over the eight lessons ($slope = -0.01$, $p = .04$, $d = -.75$). This means that over time there is a decrease in the degree to which the teachers use a syntactic category for some uninterrupted number of utterances, which is imitated by the students at some point during the observation. Calculations of the horizontal line structures (LAM$_H$) revealed that the extent to which students were ‘trapped’ into displaying the same syntactic category as their
teacher also decreased convincingly over time \((slope = -.01, p = .02, d = 2.02)\). Lastly, the Monte Carlo analysis of the slope of the relative difference of \(\text{LAM}_V\) and \(\text{LAM}_H\) revealed a significant change over time, but with a less than 'small' effect size \((slope < .01, p < .01, d = .19)\). This specific pattern of results, that is, the decreases in both \(\text{LAM}_V\) and \(\text{LAM}_H\) over time with constant zero relative difference, can be interpreted as a similar decrease of the influence regarding syntactic complexity of teachers on students and of students on teachers. That is, teachers and students became more loosely coupled over time in a way that keeps their mutual influence equal over the lessons.

![Figure 5](image)

**Figure 5** Average laminarity \((\text{LAM}_V, \text{LAM}_H\) and \(((\text{LAM}_V-\text{LAM}_H)/(\text{LAM}_V+\text{LAM}_H))\)) over eight science lessons. Solid line indicates average and dotted line indicates the range (minimum and maximum values).
Both $TT_V$ and $TT_H$ values were all around 3 – the average vertical and horizontal lines in the recurrence plot consisted of about 3 recurrent points –, which means that teachers and students ‘trap’ each other into same syntactic categories with average durations around 3 successive utterances. A Monte Carlo analysis of the slopes provided no evidence for changes in these patterns over time ($slope\ TT_V = -0.02, p = .28, d = .84;\ slope\ TT_H = -0.05, p = .11, d = - .88$). Next, a Monte Carlo analysis of the relative difference of $TT_V$ and $TT_H$ over time did not provide evidence for change ($slope < .01, p = .28, d = 1.69$), with average values varying slightly around 0. This means that the analysis of TT provided no indications that teachers and students asymmetrically influenced each other, nor that there were changes over time in the mutual influence, with respect to utterance length in the different categories of syntactic complexity.
A Monte Carlo analysis provided weak support for a decreasing trend of MaxL\textsubscript{V} over time (slope = -.25, p = .06, d = -2.02). In other words, the maximum episode that a teacher was 'trapped' into a same level of syntactic complexity as students were at some point showed a small decrease over the lessons. This indicates that teachers became less strongly influenced by students. Calculations of the horizontal line structures revealed no support for changes in the MaxL\textsubscript{H} over time (slope = -.06, p = .38, d = .64). Last, the relative difference score provided no support for change over time (slope < .01, p = .30, d = -2.17). This means that the coupling
between teacher and students remained equally strong over time. The relative difference of MaxL_V and MaxL_H is only slightly above zero, indicating no real asymmetry in this respect, although there is considerable variation among teachers.

Figure 7 Average maximum line (MaxL_V, MaxL_H, and ((MaxL_V-MaxL_H)/(MaxL_V+MaxL_H))) over eight science lessons. Solid line indicates average of teachers and dotted line indicates the range (minimum and maximum values).
6.3.3 Relative strength of syntactic coordination for the different syntactic categories

First, we plotted the CRP(color) of no sentence and calculated the RR_{no utterance}. A Monte Carlo analysis of the slope over the eight lessons did not provide evidence for change over time (slope = .002, p = .23, d = .16). RR_{simple sentence} showed a convincing (sudden) decrease over time (slope = -.02, p < .01, d = -1.07), which means that simple sentences became less recurrent over time. From figure 8 it is apparent that recurrence of simple sentences changed abruptly after lesson 3. Thirdly, for the category complex sentence the RR_{complex sentence} increased convincingly over the eight lessons (slope = .004, p = .01, d = 3.02), which means that complex sentences became more recurrent. These results indicate changes in the coordination of syntactic structures; decreasing coordination for simple sentences and increasing coordination for complex sentences.
Figure 8  Overview of recurrence rates per syntactic category (no sentence, simple sentence, complex sentence) over time. Solid line indicates average and dotted line indicates the range (minimum and maximum values).

6.4 Discussion

The contribution of this study has been to provide insight into how syntactic coordination within teacher-students interactions change during an intervention by applying chromatic and anisotropic CRQA to each of the lessons across the course of an intervention.
6.4.1. Conclusion and interpretation of results

One of the main aims of the intervention was to bring about behavioral change among teachers, by changing the interaction, and by raising awareness of the importance of using complex language in science education. This was done by providing teachers with information on effective ways of introducing (‘modeling’) and evoking more sophisticated language use from their students, which was practiced in the lessons and reflected upon in the video feedback coaching sessions. The analysis of the proportion of utterances in the specific syntactic categories indicated significant changes over time. Both teachers and students started using more complex sentence structures and less simple sentence structures. An important observation was that changes in students’ use of simple sentences occurred at lesson 4, which is right after the first coaching session. On the basis of pre- and post-measurements comparisons, we can conclude that there is change over time with regard to syntactic complexity. However, as stated in the introduction, these global measures do not provide information on how change occurs on the micro level of the interaction.

For this reason, chromatic CRQA was used to analyze the structure of syntactic coordination for the different levels of syntactic complexity. The results indicated changes in the proportion of recurrent points of simple sentences and complex sentences. In case of simple sentences, teachers and students became more loosely coupled over time, where in case of complex sentences, teachers and students showed increasing coordination. This indicates that the structure of the conversation changed from more strongly coordinated simple sentences before the intervention to more strongly coordinated complex sentences. Again, findings indicate that a transition occurred after lesson 3; the syntactic coordination regarding simple sentences changed from tightly coupled towards more loosely coupled.

When investigating the relative strength and direction of syntactic coordination between teachers and students, it became clear that in the course of the intervention, the language of teachers and students became more loosely coupled over time, mainly expressed by the decrease in the amount of laminar states (LAM). This can be an indication that the teacher-student interaction became more flexible. The influence of both teachers and students was equally strong at the start of the intervention, but changed towards more asymmetry in the coupling in the way that students became somewhat more leading in the interaction. However, the effect size of this result was small. Since the intervention aims at stimulating students to talk and elaborate on their responses, the slight changes towards more ‘influence’ of students – in a dynamic way – on the syntactic coordination are an interesting and supportive result.

Earlier studies have shown that speakers tend to align their speech towards syntactic coordination (Branigan, Pickering & Cleland, 2000; Dale & Spivey, 2006; Van Dijk et al., 2013; Tamis-LeMonda & Bornstein, 2002). Our study investigated syntactic coordination over the course of an intervention and it was found that this coordinative process changed over time. Laminarity of vertical and horizontal lines decreased over time – there were less recurrent points on the horizontal and vertical lines –, which means that the coupling between teachers and students regarding syntactic complexity became more flexible. The recurrence rate of
simple sentences decreased – less matching of simple sentences –, and the recurrence rate of complex sentences increased – more matching of complex sentences – over time. This indicates a stronger coupling between teachers’ and students’ complex sentences, which is an important finding in the light of the intervention under investigation. With regard to the direction of this coordination, there were no changes over time. Science lessons provide a highly suited context for students to become (more) proficient in using complex syntax to express complex ideas, as this requires exposure to various ways in which sentences can be connected through combining clauses and through the use of conjunctions to express particular relations between clauses. The application of CRQA techniques provides new (additional) insights and contributes to a better and unique understanding of the underlying dynamics of syntactic coordination. The measures of coordination – measures that were derived from the CRP – inform us about the process of change in terms of changes of teachers and students, and the coordination between these subsystems. The CRQA techniques also enable us to tear apart the respective contributions of each of the two contributing subsystems (i.e. teachers and students) to the dynamics.

In the context of language learning, it is important for teachers to be aware of the bidirectional character of language use and the opportunities for advanced language learning of students. By the mutual influences of using increasingly complex language, teachers and students create an upward spiral of the complexity of their language use. For teachers, this reciprocal adaptation means that they need to learn how to carefully listen to the verbal utterances of their students in order to respond contingently. These contingent teacher responses need to be tailored to the current verbal abilities of students, and they also need to be challenging in order to stimulate students to advance their language skills.

6.4.2 Limitations and future research

This paper adopted a relatively novel methodological approach, where data consisted of observations of real-time interactions between teachers and students across the course of an intervention. This kind of data was necessary for analyzing the underlying dynamics of syntactic coordination. Each observation was quantified in order to create event series that formed the input for the CRQA. The number of cases that are used in this study (seven teacher-student dyads) is relatively large for performing such an in-depth analysis of coordination processes, which is possible through the application of CRQA. This is an illustration of the inevitable trade-off between the depth of analysis and the number of cases that can be analyzed. In order to ultimately make generalizations about the real-time processes, we need much more in-depth studies, such as the one described in the current paper.

The methodological decision to include event series instead of time series is a limitation of this study in the way that it did not allow us to investigate the contribution of meaningful pauses and other relevant temporal aspects of coordination (e.g. leader-follower dynamics) in the interaction. Mercer and Dawes (2008) argue, for instance, that pauses after posing a question gives students more time to think, which leads to greater learning gains. The structure
of a conversation between teacher and students is partially determined by meaningful pauses, and therefore, future studies should be undertaken to explore how these pauses contribute to the underlying dynamics of kindergarten science discourses.

Another limitation is that, for the current analyses, the students are considered ‘the speaking partner’ of the teacher during the small group science activities. However, it would have been interesting to include analyses of the contributions of individual students – and interactions between those students – as well. The current data did not allow us to investigate the contributions of each of the individual students to the interaction since the CRQA technique requires a continuous data stream. Additional research is necessary in order to shed light on the ‘influence’ that individual children have on this process of syntactic coordination during science lessons, and whether this dynamics relies on only one or two individual students. The question arises whether existing analyses are capable of capturing these complex interaction processes between multiple speakers.

Being limited to small group science activities, the results do not inform us about the temporal and dynamic structure of science conversations during natural whole-classroom situations. The small-group teaching activities were used for two reasons: to optimize the training conditions for teachers and for practical reasons such as visibility and audibility on camera. In this light, additional research is needed in order to investigate syntactic coordination between teachers and students in natural science whole-classroom settings. The current study is a first step towards greater understanding of this process in real-time teacher-student interactions during small group activities. On the other hand, small group teaching activities become an increasingly common form of education, because this allows for more intensive interaction.