



# Teachers' collaborative knowledge building in professional learning communities: connecting interaction patterns to learning gains

Marloes M. H. G. Hendrickx<sup>1</sup> · Marieke C. G. Thurlings<sup>1</sup> · Perry Den Brok<sup>2</sup>

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## Abstract

Teacher professional learning communities (PLCs) have the potential to result in teacher professional development, provided that effective communication takes place during PLC meetings. Building on the perspective of collaborative knowledge building, this study examined teachers' interaction patterns during these meetings. Connections were explored between teachers' self-perceived learning gains from a PLC and the interaction patterns that occurred. From a larger set of PLCs in the Netherlands, four cases were selected that differed regarding teachers' learning gains profiles. Orbital decomposition analysis, a technique used to study emerging patterns in complex dynamic systems, was used to examine the extent to which interaction patterns were characterized by conversational moves associated with knowledge building. Results from these analyses showed that in general, all PLCs showed relatively few knowledge-building patterns. However, the low-gains PLC was a bit more focused on exchanging information and opinions. High-gains PLCs' interactions were characterized more by open and involved communication. Conversation in mixed-gains PLCs revealed a connection between teachers' knowledge gains and question–answer patterns, and between teachers' changes in beliefs and elaborating upon opinions. Together, these results point to qualitative differences in the interactions of teacher PLCs who experience higher versus lower learning gains. Implications for the role of the facilitator are discussed.

**Keywords** Professional learning communities · Conversational moves · Teacher-perceived learning · Orbital decomposition analysis

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✉ Marieke C. G. Thurlings  
m.c.g.thurlings@tue.nl

Marloes M. H. G. Hendrickx  
m.m.h.g.hendrickx@tue.nl

<sup>1</sup> Eindhoven School of Education, Eindhoven University of Technology, Eindhoven, the Netherlands

<sup>2</sup> Education and Learning Sciences, Wageningen University and Research, Wageningen, the Netherlands

## Introduction

In the past decades the popularity of teacher professional learning communities (PLCs) as a form of teacher professional development has increased, referring to a group of teachers 'sharing and critically interrogating their practice in an ongoing, reflective, collaborative, inclusive, learning-oriented, growth-promoting way, operating as a collective enterprise' (Stoll et al., 2006, p. 223). Recent (review) studies have shown that participation in a PLC has the potential to lead to changes in teachers' knowledge, beliefs, identity, and classroom behavior (e.g., Barr & Askell-Williams, 2020; Dogan et al., 2016; Prenger et al., 2019; Vescio et al., 2008; Vossen et al., 2020), and eventually to improved student outcomes (Lomos et al., 2011; Vescio et al., 2008). However, studies have found a variety in the extent to which this potential is met, that is, how much change in teachers' knowledge, attitudes, and classroom behavior is actually achieved as a result of participation in PLCs. This shows that merely creating a setting in which teachers regularly meet and can interact does not necessarily lead to teacher learning (Lomos et al., 2011; Vossen et al., 2020).

To understand and to be able to foster teacher learning within PLCs, the interaction taking place among its members needs to be carefully scrutinized (Little, 2002, 2003; Walkoe & Luna, 2020), and knowledge-building activities must be pinpointed to localize teacher learning opportunities (see Horn et al., 2017; Popp & Goldman, 2016). Existing research has often used an intervention-outcome model, overlooking the conversational process by which these outcomes are reached (see Vrikki et al., 2017) or has only described interactions, without examining associations with teacher learning (for a recent review, Lefstein et al., 2020). Existing work that does analyze the extent to which interactions in PLC contribute to teacher professional development tends to use observation categories that are a priori assumed to be associated with high-quality, deep learning, or knowledge-building, without an empirical connection to actual learning gains (e.g., Popp & Goldman, 2016; Vrikki et al., 2017; see Walkoe & Luna, 2020). The current study aimed to bridge this gap by examining connections between teachers' self-perceived learning outcomes and their interactions in PLC meetings. The results of our study can help inform interventions aimed at boosting teacher professional development in PLCs and, ultimately, student learning.

## Teacher learning in a PLC

In teacher PLCs, teachers collaboratively discuss their teaching, with the general aim of improving their practice. Five interconnected aspects define the concept of a PLC (see Kruse et al., 1995; Lomos et al., 2011): reflective dialogue, deprivatization of practice by giving feedback on instruction, collaborative activity, shared sense of purpose, and a collective focus on student learning. These characteristics are intertwined and operate interdependently (Bolam et al., 2005; Lomos et al., 2011). In a way, PLCs are a means to an end, and not a purpose in themselves (Stoll et al., 2006); the aim is to increase student learning, by improving teachers' knowledge, beliefs, and classroom practices. Moreover, PLCs also serve as an environment for teacher socialization, connecting teachers to one another and providing a space to develop common ground. Compared to other teacher professional development activities such as lectures or workshops, PLCs can have a more sustainable character, as the newly acquired knowledge and skills are directly practiced in the classroom, whereupon experiences are discussed with relevant colleagues.

Clarke and Hollingsworth's (2002) interconnected model of teacher professional growth is helpful in unraveling teacher learning through PLCs. Clarke and Hollingsworth

distinguished four domains in which change can occur: the external domain, the personal domain, the domain of practice and the domain of consequence. The external domain consists of external sources of information or stimuli, including participation in a PLC. The personal domain encompasses the teacher's personal knowledge and belief system. The domain of practice refers to professional experimentation in the classroom. The domain of consequence entails the salient outcomes of teacher behavior, including changes in student engagement or outcomes. The four domains are interconnected through pathways of reflection and enactment (Clarke & Hollingsworth, 2002). For instance, reflecting on experiences may lead to changes in knowledge and beliefs, whereas the deliberate experimentation based on a change in teachers' knowledge is considered enactment. In the current study, the focus was on teacher change in the personal domain (increased knowledge and beliefs), as well as the domain of practice (experimentation with differentiated instruction in practice). Participation in the PLC (external domain) was considered to drive these changes, making reflection based on individual and shared experiences a social endeavor (see Vrikki et al., 2017).

### Analyzing teacher interactions: conversational moves

If PLC participation can drive changes in the interconnected domains as indicated above, which elements of the interaction make this change possible? To find an answer to this question, a wealth of perspectives has been applied to analyzing teacher interaction (see Lefstein et al., 2020). Often, analyses are focused on general constructs, such as trust or reflection. These constructs are often abstract, which makes it difficult to analyze them and to provide PLC facilitators with practical suggestions regarding effective interaction. In an attempt to focus on practical moment to moment building blocks for these bigger constructs, the current study examined conversational moves. Conversational moves, and its related terms discourse moves, dialogue moves, interaction functions, or dialogue acts, refer to the actions conversation partners undertake to take the conversation forward (Warwick et al., 2016). The construct is associated with theoretical perspectives that emphasize the social aspect of learning, including sociocultural theory and the idea of Communities of Practice (Mercer 2004; Warwick et al., 2016).

To value the conversational moves as put forward by the teachers, we connect these to the framework of knowledge building (see Gutiérrez-Braojos et al. 2023; Scardamalia & Bereiter, 2014). Collaborative knowledge building, mostly applied in research on students' (computer-supported) collaborative learning, refers to the process in which learners as a group develop their knowledge, build shared knowledge, or solve problems through a series of coordinated interactions (Zheng et al., 2023). Through discourse, participants actively improve on ideas; learners create and add value to the shared knowledge base in the community (Scardamalia & Bereiter, 2014). Connecting the work on knowledge building to PLCs, Popp and Goldman (2016) discerned conversational moves that were strongly related to knowledge building (e.g., suggestions, elaboration, and opinions) versus those moves that were only limitedly related to knowledge building (e.g., informing, simple agreement). They found that teachers generally were limited in their knowledge-building discourse, particularly when describing and discussing their instructional practices. In the current study, we view collaborative knowledge building to be a central aspect of successful PLCs (see Stoll et al., 2006). That is, knowledge building is a collaborative effort, where all community members are valuable contributors to the community's shared understanding (Popp & Goldman, 2016, see also Scardamalia & Bereiter, 2014).

However, by a priori describing certain moves as being related to knowledge building and excluding others from this category, Popp and Goldman (2016) have accepted this distinction as is, without empirically connecting the categories to teachers' knowledge gains. As Lefstein et al., (2020, p.8) noted, "the case for the importance of certain generative elements of discourse has been substantiated primarily by logical argument, rather than evidence showing the effects of discourse on actual teacher development or even student learning". The current study helps to find those discourse elements that are worthwhile exploring further as possibly connected to outcomes.

## The present study

The current study aimed to connect teachers' perceived learning gains to the interactions that took place during conversations in professional learning communities. From nine participating PLCs, we selected four cases that differed strongly in the amount of change they reported and closely examined interaction patterns. As indicated by Rummel et al., 2008, contrasting case analysis is a promising approach to relate collaborative processes to outcome criteria, by making important differences between groups salient (see Marton, 2006), exploiting variability among cases and facilitating the discovery of appropriate explanations for these differences (see Firestone, 1993). Four cases were selected instead of examining all nine to delve deep into these cases so to gain rich insights and understanding of their interaction patterns. Our main research question was: How do conversational moves patterns in teacher PLCs differ for PLCs that have contrasting levels of teacher-reported learning gains?

We expected that groups where higher learning gains were reported would have more conversational moves that are considered to contribute to knowledge building, and thereby generative discourse (Lefstein et al., 2020; Popp & Goldman, 2016), including suggestions and opinions, supported by elaborated argumentation. On the other hand, we expected to find more flat descriptions/pieces of information, not connected to opinions or suggestions, in groups with lower gains.

## Method

### Participants

Nine PLCs participated in this study, consisting of 53 teachers from five schools for secondary education in the Netherlands. Teachers within one PLC all taught at the same school. Although teachers were acquainted with one another, they had no prior experience as a PLC. PLCs met four to six times during one school year, for meetings that lasted 1 to 2 h. Only those teachers who were present during at least two meetings were considered active members of the PLC and therefore included in the study. Four teachers did not meet this requirement, because of personal situations that prohibited them from joining most meetings (e.g., maternity leave, illness, changing jobs). PLCs on average consisted of 5.11 teachers (range 3–8) of whom 57.8% were women (range 25–100%). Teachers had on average 16.70 years of experience (range 0–40 years). Subjects were not prespecified and included language (Dutch, German, English), social studies (History, Geography, Economics), science (Mathematics, Physics, Biology), physical education, and arts.

## Study context and procedure

The data reported on here are part of a research project on teacher professional development in PLCs in secondary education in the Netherlands. The nine PLCs that were selected for this study all had the same topic: implementing or improving differentiated instruction in their classrooms, and all had their meetings videotaped, which enabled the close analysis of their interactions. PLC members were encouraged to attend each other's lessons, or make video recordings, so they could compare and discuss their experiences using this material. In case of multiple PLCs per school, grouping was based on subject, grade levels in which the teachers taught, or practical concerns such as time slots in which all teachers were available. PLCs were facilitated by a researcher from our team, who kept minutes of the meeting and took care of the logistics regarding data collection (making video recordings, handing out questionnaires).

## Instruments

### Learning gains

To examine teachers' self-perceived learning gains, we used a questionnaire that was completed at the end of the final PLC meeting, consisting of five items reflecting learning domains, based on the four domains of change by Clarke and Hollingsworth (2002). Participating in the PLC was considered the external domain, with its possible effects on the personal domain (*I gained knowledge about differentiated instruction; I came to think differently about differentiated instruction*), the domain of practice — both actual and intended (*I have implemented the things we discussed in my lessons; I am going to implement the things we discussed in my lessons in the next months*), and the domain of consequence (*Differentiated instruction has positive effects on my students*). Participants' answers were collected on visual analogue scales (see Gift, 1989), where participants are asked to indicate their subjective response by marking their position on a continuous line. The ends of the line were demarcated with “not at all” and “very much”. The advantage of using a virtual analogue scale is that it provides a more nuanced and continuous measurement compared to discrete scales like Likert scales, where respondents are limited to selecting from a fixed set of options. We used a ruler to measure how far along each line the participant's response was marked, and divided this number by the total length of the line to create a proportion score ranging from 0 to 1.

### Conversational moves

Conversational moves were coded in the meeting transcripts of all meetings. As a first step, off-topic conversation that was not about teaching was excluded for analysis from the body of interaction. Second, we coded each teacher comment for the conversational move the teacher was conveying (event sampling). The unit of analysis was the meaningful unit within each turn. That is, within each turn, every utterance by a teacher that could be considered a new conversational move was coded.

The coding system that was applied was based on existing coding systems from the field of group research in general (Interaction Process Analysis; Bales, 1950) combined with work from the field of teacher professional development research (Popp & Goldman,

**Table 1** Coding system for conversational moves

Code	Meaning of the code	Letter
Argument	Explaining, elaborating, argumentation.	A
Elicit	Asking for something, eliciting a response. Does not have to be a real question, could also be imperative.	E
Inform	Sharing something within the group, factual information, describing.	I
Listen	Short reaction to what has just been said, without content. Literally repeating words/sentences.	L
Opinion	Providing an opinion, evaluating, judging. Both positive and negative.	O
Rephrase	Restating what has been said in one's own words; understanding. Summarizing.	R
Suggest	What someone (self or other) could do differently in the future. An idea, an action.	S

2016). The coding system was adapted during try-outs based on transcripts that were available from PLC sessions outside of the current body. The first two authors discussed the meaning of the codes and their demarcations. Decision rules were also discussed with the third author. This resulted in the final set of codes that is shown in Table 1.

Inter-rater reliability for this set of codes was addressed in two steps. First, the coders had to agree on segmentation, that is, how to decide whether a turn needed to be split into multiple conversational moves (see Strijbos et al., 2006). One randomly selected transcript from outside the body of transcripts for the current study was independently segmented by the first two authors, so purely deciding on whether a turn consisted of one or multiple moves and not coding those conversational moves yet. Agreement was 82.9%, so the two coders reliably segmented the turns into meaningful units for the analysis of the moves.

Step two of the interrater reliability process was to reliably assign conversational moves codes from Table 1 to each of those segments. To this end, Cohen's kappa was applied to independent coding of three randomly selected transcripts, again from outside the research corpus. Cohen's kappa over the three transcripts was 0.85 (range from 0.79 to 0.94 for each transcript separately), showing excellent agreement. Based on these results, the first two authors each coded half of the transcripts for the four PLCs involved in this study.

## Defining contrasting cases

To examine differences between PLCs with high versus low learning gains, contrasting cases were found based on the teachers' answers on the learning gains questionnaires. Table 2 shows the teacher-reported learning gains scores for the different domains: personal (knowledge, beliefs), practical (current and as intended in the future), and teacher-perceived consequence (teacher-envisioned effects on student learning). We highlighted group-level gain scores on the domains that were one standard deviation above or below the average of all nine participating teacher groups (see Table 2). First, we defined which cases were contrasting in terms of the highest versus lowest overall change. Second, to understand perceived learning gains in a particular domain, we included mixed-gains cases well.

PLC1 had by far the highest learning gains, with all domains scoring above  $+0.5SD$  or even above  $+1SD$  compared to the overall means for these domains. PLC3, on the other hand, reported the lowest learning gains, with all but one domain scoring lower than  $-0.5SD$  or even below  $-1SD$ . PLC5 and PLC6 both had a mixed learning gains profile: in PLC5, teachers reported not to have gained much knowledge, although their beliefs

and practice did change a lot (the high-beliefs/low-knowledge PLC). To the contrary, in PLC 6 teachers did report increased knowledge and future implementation plans but indicated that their beliefs had hardly changed (the high-knowledge/low-beliefs PLC). These four PLCs are considered the contrasting cases.

## Analysis

The first step in our analysis was to compare the four contrasting cases in terms of the most salient composition and context aspects (i.e., group size, number of meetings, attendance, teaching experience and subjects).

Second, differences regarding frequencies of conversational moves were analyzed. To this end, we computed the proportion of each conversational moves score as compared to the total amount of moves for each PLC. This provided us with an overview of the specific moves the members of the PLCs were using more and less often. However, the coding and counting in frequency tables is limited in the sense that it only reflects how big the separate piles or stacks of individual contributions were, rather than revealing the dynamics of interaction by connecting the individual contributions in a sequential approach. Such a sequential approach adds the possibility to get a grasp of the interaction patterns as they unfold, that is, the back-and-forth actions and reactions by the different group members in a PLC.

Therefore, as a third analysis step interaction patterns were analyzed, using orbital decomposition analysis (OD; Guastello, 2000), with the computer software ORBDE (Pessini & Guastello, 2014). OD is a technique for identifying recurring patterns in string data, such as the series of consecutive conversational moves for each PLC. The computational technique behind OD is based on symbolic dynamics, which involve the extraction of patterns from a series of events (Guastello, 2000). The focus of the current study was on

**Table 2** Learning gains from participation in PLCs as reported by teachers

PLC	N	Personal domain				Domain of practice				Domain of consequence	
		Knowledge		Beliefs		Implementation (current)		Implementation (intended)		Effects on students	
		M	SD	M	SD	M	SD	M	SD	M	SD
All	39	.58	.23	.52	.28	.69	.24	.71	.24	.58	.21
<b>PLC1</b>	<b>5</b>	<b>.83</b>	<b>.09</b>	<b>.76</b>	<b>.19</b>	<b>.85</b>	<b>.10</b>	<b>.86</b>	<b>.09</b>	<b>.79</b>	<b>.20</b>
PLC2	5	.45	.28	.42	.36	.56	.38	.57	.35	.55	.09
<b>PLC3</b>	<b>4</b>	<b>.35</b>	<b>.19</b>	<b>.16</b>	<b>.10</b>	<b>.61</b>	<b>.31</b>	<b>.48</b>	<b>.41</b>	<b>.47</b>	<b>.24</b>
PLC4	4	.76	.15	.55	.35	.84	.09	.73	.18	.58	.08
<b>PLC5</b>	<b>3</b>	<b>.47</b>	<b>.21</b>	<b>.79</b>	<b>.15</b>	<b>.84</b>	<b>.11</b>	<b>.92</b>	<b>.05</b>	<b>.82</b>	<b>.16</b>
<b>PLC6</b>	<b>3</b>	<b>.75</b>	<b>.04</b>	<b>.21</b>	<b>.13</b>	<b>.70</b>	<b>.24</b>	<b>.92</b>	<b>.05</b>	<b>.62</b>	<b>.10</b>
PLC7	6	.55	.14	.50	.28	.54	.28	.63	.18	.42	.26
PLC8	4	.66	.16	.66	.16	.77	.11	.75	.05	.48	.07
PLC9	5	.42	.10	.54	.10	.62	.19	.65	.14	.56	.22

Possible range in scores is 0–1. *N* refers to the learning gains questionnaire sample size. PLCs presented in bold represent the contrasting cases that were selected based on differences from the overall mean in standard deviations

the key patterns that characterized the interaction within each PLC. So, OD analyses were run on the combined set of all meetings per PLC. That is, the series of events in this case describes all the recorded and coded interactions the teachers of one PLC had.

The start of OD analysis is to empirically determine the optimal string length  $C$  of the patterns, that is, the number of behavioral events that together form a set that often recurs over the interaction course (see Pincus & Guastello, 2005). The length of recurring patterns is important to identify those patterns that are most relevant to describe the rhythm of the group dynamic.  $C$  is based on entropy and goodness of fit measures (for an explanation and guidelines see Guastello et al., 1998; Pincus, 2001; Pincus & Guastello, 2005). To ensure reliability for this process, optimal string length was initially determined by the first two authors separately, who had 100% agreement. Optimal string length per transcript ranged from 4 to 6. In order to have a relevant comparison of the contrasting cases, the same  $C$  length was chosen for all PLCs. A  $C$  of 4 was considered the general optimum, as (a) 4 was the optimal string length in 67% of the findings and (b) strings of length 5 or 6 also contain strings of length 4.

Next, OD identifies those dynamic behavior sequences of the found string length that recur in the data, which can then be interpreted conceptually. We examined the top 10 patterns in conversational moves for each of the contrasting cases, to show the patterns that most often occurred within the PLCs.

## Results

### Preliminary analyses

Before delving into the interaction dynamics, we examined whether structural differences existed between the PLCs in terms of context and group composition. Table 3 shows the context and composition aspects of the four learning gains cases. The high-gains PLC had on average the smallest amount of teaching experience. Four of the seven teachers in this PLC had four years or less of teaching experience. The low-gains PLC had the lowest presence rate of the four PLCs, with on average 70% of the group members present, compared to 81% to even 100% for the other PLCs. Both mixed groups differed from the others in their size (only 3 participants). They also had fewer meetings, which were well attended.

### Analysis of conversational moves

#### Frequencies of conversational moves

Table 4 shows the frequency distribution of the conversational moves categories, for the total sample as well as each of the contrasting cases. As shown in the most left column, PLC-participants in general mostly informed each other (38.2% of the utterances), followed by giving opinions (24.0%). Eliciting and Suggestions both comprised roughly 10% of the utterances. Teachers hardly elaborated on their suggestions and opinions by using arguments (2.8%).

Contrasting the high and low learning gains cases, teachers in the low-gains PLC seem to have been involved mostly in rather independently telling their own stories; *inform* and *opinion* were relatively frequent whereas *elicit*, *rephrase*, and *listen* were infrequent. Teachers in the high-gains PLC on the other hand gave fewer information and opinions, but were more involved in eliciting and rephrasing, which seems to indicate a stronger involvement with what others are contributing to the conversation. Moreover, they gave more than



twice as many arguments than the teachers in low-gains group, albeit still a small amount of the total interaction.

A comparison of the mixed-gains PLCs shows that the high-beliefs/low-knowledge PLC had fewer instances of teachers informing each other and more suggestions than the high-knowledge/low-beliefs PLC. Both groups gave relatively many opinions and rephrased each other a lot.

### Patterns in conversational moves

Table 5 shows the top-10 patterns in the interaction of the four cases. There is no difference in the pattern the teacher groups were most attracted to: a sequence of four serial *Informs*, indicating a sequence of information that is shared among members. PLCs did differ however in the strength of this pattern, as shown by the percentage of the total body of interaction that followed this pattern: 6.4% for the group that had the lowest learning gains, compared to 1.8–3.7% for the other groups. More differences occurred after the first pattern. The high-gains PLC's top-10 patterns are characterized by eliciting and providing information. In contrast, the low-gains PLC had serial turns of informing in all their top-10 patterns. The excerpts below illustrate the different approaches to asking questions in between adding information. The first is a piece from the high-gains group, where teachers discuss a lesson by one of them. This excerpt is illustrative of how asking for information can be helpful in the learning process:

*Emily:* But what was the reason you were so hesitant?

*John:* I actually don't remember anymore.

*Luke:* Did you feel pressure?

*John:* Yes, they [the students] were of course talking, maybe that was it, they were talking. But yes, they were talking about what they were doing. Yes, but there were two friends in the middle who at some point started bickering and some kind of discussion arose between those two guys. And that was a bit...

Emily starts by seeking to understand the reason behind John's hesitation, prompting John to reflect and provide an explanation. John admits to not remembering the reason, which opens up the conversation for further probing. Luke suggests a possible reason (pressure), guiding John to consider and elaborate on this possibility. John then provides a detailed account of the situation, describing the environment and interactions that might have contributed to the hesitation. The interaction is exploratory and reflective, with Emily and Luke asking questions that prompt John to provide detailed explanations and context. They are involved together in knowledge building by uncovering underlying reasons and specific details about the situation.

The next excerpt shows part of a conversation on a lesson from the low-gains PLC. This group also discussed a lesson from one of the teachers after it was taught. In this particular excerpt, two teachers talk about the curriculum:

*Hugh:* Yes, but in the second year, percentages don't really come back, only prior knowledge. That is, in economics.

*Iris:* But when do yours [students] encounter the ratio table?

*Hugh:* First year.

*Iris:* First year already?

**Table 3** Context and composition aspects for the learning gains cases

	PLC1 (high gains)	PLC3 (low gains)	PLC5 (mixed, high beliefs)	PLC6 (mixed, high knowledge)
Group size	7	5	3	3
Number of meetings	6	6	5	4
Total number of conversational moves	3250	2027	3423	2331
Presence <sup>a</sup>	0.81	0.70	1.00	0.92
Teaching experience (years)	9.20	14.00	20.67	16.33
Subject	Different subjects	Different subjects	Same subject area	Different subjects

<sup>a</sup> Presence was calculated as the average percentage of group members who were present at each meeting; a presence score of 1 indicates that all teachers were present at all times, a presence score of .5 indicates that on average half the teachers were absent each meeting

*Hugh:* In the first year, there is a whole chapter on percentages. Three chapters, first percentages, then percentage decrease and increase, and then application.

*Iris:* Do they also have new and old?

*Hugh:* No, they don't know that, it doesn't come up

In this piece of conversation, first Hugh shares information about the curriculum, indicating that percentages are not revisited in the second year in the current setup of the curriculum. Iris asks for specific information about when the ratio table is taught, prompting Hugh to provide a timeline. Hugh responds with a concise answer, indicating the first year. Iris expresses surprise and seeks confirmation, which encourages Hugh to elaborate. Hugh provides a detailed breakdown of the curriculum, explaining the structure and content of the chapters on percentages. Iris asks for further details about the curriculum, specifically about the concepts of "new" and "old", which refer to steps in computing percentages (e.g., a product's new versus its old price). Hugh clarifies that these concepts are not covered, again providing a clear and direct answer. The interaction is more straightforward than in the first excerpt, with Iris asking for specific information and Hugh providing clear, concise answers. This excerpt primarily involves asking for and sharing information rather than building new knowledge.

In the high-beliefs/low-knowledge PLC, patterns 2–5 all comprise consecutive opinions, which likely added to the members' change in beliefs; not only were opinions expressed a lot (see also Table 4), but they were presented with opposing or additive opinions, building on each other to co-construct a belief system regarding differentiated education. An example is shown in the excerpt below, coming from the PLC's first meeting. During this meeting, teachers are figuring out what they want to discuss in their group, as related to differentiated instruction. Differentiating on gender is brought up as a possible topic, upon which teachers discuss whether they notice any differences between boys and girls.

*Mary:* Yes, in terms of their behavior. The girls are somewhat more serious. They are more committed. Boys are more playful, with every eye contact.

*Ingrid:* Less interested

*Louise:* I'm not sure they are or that they only give off that impression. Like they are not interested.

**Table 4** Frequencies of conversational moves in all PLCs and the contrasting cases

Category	All PLCs		PLC1 (high gains)		PLC3 (low gains)		PLC5 (mixed, high beliefs)		PLC6 (mixed, high knowledge)	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
Argument	629	2.8	114	3.5	32	1.6	70	2.1	46	2.0
Elicit	2659	12.0	508	15.8	217	10.8	322	9.8	190	8.2
Inform	8666	39.1	1359	42.3	993	49.4	1041	31.8	938	40.6
Listen	1151	5.2	103	3.2	19	0.9	134	4.1	66	2.9
Opinion	5444	24.6	624	19.4	580	28.8	1001	30.5	703	30.4
Rephrase	1466	6.6	246	7.7	36	1.8	358	10.9	233	10.1
Suggest	2152	9.7	260	8.1	134	6.7	351	10.7	137	5.9

*Mary:* They are active though.

*Ingrid:* But they are triggered less by the lessons than the girls.

*Louise:* Maybe they are more triggered by all kinds of distractions in the classroom.

*Ingrid:* I wonder how these things work, I find it really interesting.

In this excerpt, Mary initiates the discussion by offering an observation about gender differences in student behavior, stating that girls seem more serious and committed while boys are more playful. Ingrid briefly adds that boys appear less interested, which Louise questions, suggesting that boys might only give off that impression. This exchange highlights varying perspectives and encourages further exploration of the topic. Mary counters by noting that boys are active, while Ingrid elaborates that boys are less engaged by lessons than girls, potentially hinting at a need for different teaching approaches. Louise then proposes that boys might be more easily distracted, adding another layer to the discussion. Ingrid concludes with a reflective comment, indicating a curiosity about the underlying

**Table 5** Top 10 interaction patterns in the learning gains cases

#	PLC1 (high gains)		PLC3 (low gains)		PLC5 (mixed, high beliefs)		PLC6 (mixed, high knowledge)	
	Pattern	Freq (%)	Pattern	Freq (%)	Pattern	Freq (%)	Pattern	Freq (%)
1	IIII	89 (2.7)	IIII	129 (6.4)	IIII	63 (1.8)	IIII	86 (3.7)
2	IEII	72 (2.2)	IIIO	59 (2.9)	I000	35 (1.0)	IOIO	47 (2.0)
3	EIEI	62 (1.9)	IIIEI	53 (2.6)	000I	33 (1.0)	IIIO	44 (1.9)
4	IIIEI	60 (1.8)	IIOI	53 (2.6)	0000	32 (0.9)	0000	42 (1.8)
5	EIII	47 (1.4)	OIII	52 (2.6)	OOIO	32 (0.9)	IIOI	40 (1.7)
6	IEIE	45 (1.4)	IOII	50 (2.5)	IEII	31 (0.9)	OIOI	40 (1.7)
7	IIOI	42 (1.3)	IEII	50 (2.5)	OIOO	31 (0.9)	OIII	39 (1.7)
8	IOII	39 (1.2)	EIII	44 (2.2)	IIIEI	29 (0.8)	IOII	35 (1.5)
9	IIIE	38 (1.2)	IIIE	42 (2.1)	OIIO	29 (0.8)	000I	30 (1.3)
10	IOIO	35 (1.1)	OOII	41 (2.0)	IOOI	29 (0.8)	I000	29 (1.2)

E Elicit, I Inform, O Opinion

reasons for these behaviors. The teachers build on each other's points by offering complementary and sometimes contrasting views, collectively deepening their understanding of student dynamics in the classroom. This excerpt illustrates these teachers' willingness to explicate the opinions and beliefs they held, to challenge these, and to find out together "how these things work". These discussions may have resulted in the change in beliefs that the teachers experienced.

The high-knowledge/low-beliefs PLC also had many opinions in their top-10 patterns, but fewer consecutive opinions and more information intertwined with them. Teachers in this PLC particularly expressed opinions regarding their colleagues' descriptions. An example of this process is shown in the next excerpt from the fourth meeting. One of the teachers, Meryem, is telling the others about an experimental lesson that she gave a few days before the meeting, applying differentiated instruction. She made three groups and provided instruction to groups 1 and 2, afterwards gave extra attention to group 2, while group 3 was working independently.

*John:* So Meryem, did the other group bother you?

*Meryem:* No, they were working quietly.

*John:* That's important, that there is a quiet atmosphere in the classroom. Because nothing is more annoying than when you are explaining something to one student another is babbling in your ear.

*Meryem:* What you could do is give the other group a sheet with the right answers or place that in a dedicated area. If students are ready, they correct their own work. You could gather the corrected work at the end.

*Laura:* That would give you more things to do, you don't want that, maybe each other?

*John:* Right, that might be even more fun. Then all groups could be mixed.

In this excerpt, the teachers quickly move from discussing their observations to offering concrete suggestions without deeply engaging with each other's opinions. John starts the conversation by asking Meryem if the other group was disruptive, to which she responds that they were working quietly. John agrees and emphasizes the importance of a quiet classroom. Meryem then proposes a solution to maintain this quiet by giving students answer sheets to self-correct their work. Laura critiques this idea, noting that it could increase workload for the teachers, and suggests an alternative where students help each other. John agrees with Laura's suggestion, noting it could be more enjoyable and foster mixed group interactions. The focus is mainly on finding practical solutions rather than exploring or building upon each other's opinions, leading to a rapid shift from problem identification to solution implementation. As this excerpt shows, teachers did share their opinions, but connected them more to specific classroom events, after which they continued on describing the next event or providing suggestions for what to do. When expressing opinions, they engaged much less in delving into those and contrasting their own opinions.

## Discussion

The present study investigated differences in interaction patterns in PLCs with contrasting levels and domains of teacher learning. By showing how interaction in a high-gains PLC differed from that in a low-gains PLC, and how interaction differed in two PLCs with an

opposite mix in their learning gains, we aimed to add to the knowledge base empirically connecting PLC interactions to teacher outcomes.

### **High-gains versus low-gains PLC**

The low-gains and the high-gains cases differed distinctly in the amount of active involvement; apart from the teachers' presence which was by far the lowest in the low-gains PLC, this was also shown in the interaction frequencies and patterns. Teachers in the low-gains PLC mainly informed each other and shared their own opinions, whereas eliciting a response and rephrasing the other's contribution were more prominent in the high-gains PLC. When questions were asked in the low-gains PLC, this was merely to elicit further information rather than to elaborate on opinions or suggestions. This difference was present in the frequencies but was particularly shown in the interaction patterns. Although both PLCs had a series of four informing moves as their most occurring pattern, this was much more frequent for the low-gains PLC than the high-gains PLC, and consecutive patterns revealed more involvement for the high-gains PLC than for the low-gains PLC. This contrast seems to be in line with Dobie and Anderson's (2015) distinction of an open discussion versus a set of serial turns. In line with their conclusion, we found an open discussion most strongly related to teacher reports of their professional development. The finding also resonates with Little's (1990, 2002) framework, where the amount of interdependence in a group of teachers makes the difference between storytelling versus joint work. Our findings further substantiate this work, showing that indeed a stronger involvement, or interdependence, may be related to teachers' learning outcomes.

### **Differences between the mixed-gains PLCs**

Two PLCs in our sample were contrasting in terms of the domains in which teachers experienced growth (see Clarke & Hollingsworth, 2002); in one PLC, teachers reported a large change in their beliefs, while they did not report to have particularly gained much knowledge, whereas in another PLC this was the other way around: teachers reported a large knowledge gain but generally held the same beliefs after participating in the PLC meetings. These cases interested us, because analyzing differences between the interaction patterns in these groups might reveal more information to connect conversational moves to teachers' learning outcomes in particular domains. It turned out that although both PLCs showed a mix of teachers informing one another, giving their opinions, and sharing suggestions, teachers in the mixed-gains group where beliefs changed most were more involved in opposing opinions and thereby challenging each other's beliefs. Teachers in the PLC where more knowledge was gained and fewer changes in beliefs were reported gave their opinions and suggestions more often in close association with a particular example of a lesson that was tried out by one of the participants. Both practices were associated with valuable results, which is a reminder that for trainers and facilitators it is important to keep in mind exactly which goals are sought after when PLCs are started.

### **The role of informing in knowledge building**

In line with existing work (e.g., Dobie & Anderson, 2015; Horn et al., 2017; Philpott & Oates, 2017), we found that teachers' interaction generally was drawn to providing

information and sharing experiences. Even the teachers who reported most learning gains had *inform* as their most occurring move and a series of four consecutive *informs* as their most recurring pattern. Apparently, teachers are only to a limited extent triggered to move to other conversational moves. Still, our results show that it would be too harsh to view informing one another as not being related to knowledge building (see Popp & Goldman, 2016; Scardamalia & Bereiter, 2014). That is, also teachers in the mixed-gains group where knowledge gains were large, yet beliefs hardly changed, were often involved in informing one another. This set of findings seems to indicate that a certain amount of informing each other is necessary for teachers to collaboratively build knowledge, provided that there is a balance with other moves, providing opinions and suggestions and elaborating on them, and generally showing an active involvement in one's own and each other's learning process. This underlines the importance of analyzing the dynamics of interaction rather than merely counting frequencies: certain moves do not seem to be in and by themselves of higher or lower value in terms of knowledge building. Rather, they need to be viewed in their context of the patterns that surround them to be appropriately valued.

### Analyzing interaction dynamics through orbital decomposition

Using orbital decomposition in educational research builds on existing methodologies by offering a novel perspective on interaction dynamics. While traditional coding and frequency analysis provide valuable insights, orbital decomposition enhances this by revealing intricate patterns and relationships within interactions. This approach allows for a deeper understanding of how ideas and influences circulate in educational settings, complementing what is already known. Orbital decomposition is particularly advantageous in studies where observation of social interaction is often used, such as studies of collaborative learning and teacher-student interactions. In collaborative learning environments, it highlights how contributions are built upon and how group dynamics evolve. In teacher-student settings, it can uncover subtle patterns of engagement and feedback, enhancing our understanding of effective teaching practices. By adding this layer of analysis, delving into the sequential patterns rather than frequencies of types of interaction, researchers can gain a more comprehensive view of interaction dynamics (Pennings et al., 2024).

### Limitations and directions for future research

The study findings need to be interpreted in the light of certain limitations. First, we have to be cautious regarding remarks about causal connections between types of interactions and teachers' professional development, because of the limited number of groups involved and the design choices that were made. Although self-reports of learning gains are important for the involved teachers (see Walkoe & Luna, 2020), self-reporting is subjective and makes it difficult to compare teachers' learning gains across teachers and PLCs. Moreover, the teachers' perceptions of higher versus lower gains may have had a range of different causes, not only the conversational moves. Other causes include the teachers' existing levels of experience and room for growth, their general attitude towards collaboration with colleagues, and possibly even group size or other basic group characteristics. Also, the number of groups involved was limited. In the future, studies based on a much larger sample of PLCs are necessary to find statistical associations between conversational moves and

learning gains. The current study hopes to inform such studies regarding the interaction patterns that might be of interest.

Second, by focusing on the analysis level of the PLC as a whole, some of the variability within the PLCs (across the different teachers or for different meetings) was lost. Research in which individual teachers are the unit of analysis has shown that teacher learning can be unpredictable and different within a teacher group, because of differences in prior knowledge and experiences (Vossen et al., 2020). As shown in Table 2, PLCs 2 and 7 had relatively large standard deviations on the learning gains scores, indicating within-PLC differences among the participating teachers. By examining overall learning gains, this variability was not considered. Future research could take this into account by examining individual participants' contributions related to their learning gains and connecting learning gains to specific meetings.

Regarding the coding system, in the current study, we have coded the types of conversational moves, not their quality. Our elaboration on the transcript in the Results section illustrates that a conversation is typically too complex to capture in a few categories. In addition to the types of conversational moves, teacher learning gains are likely strongly affected by the quality of questions, suggestions, and argumentation, and therefore future research may be well advised to incorporate quality as well as quantity aspects of conversational moves. Relatedly, it is also important to examine the content or topics of conversation (see Popp & Goldman, 2016). So, for future research it is interesting to include quality aspects as well as focus of the meetings and content of utterances.

Closely examining the role of the facilitator was beyond the scope of the present study. Yet, research indicates how important it is for the facilitator to engage teachers in productive conversations and to introduce new knowledge and perspectives (Horn & Kane, 2015; Kuusisaari, 2013; Lefstein et al., 2020). Facilitators can for instance invite teachers in a discussion on the meta-level of knowledge building, explicitly discussing the processes that take place and challenging teachers to dig deeper and engage in building on one another (e.g., Tong & Chan, 2023). Therefore, future research may profit from an approach that incorporates the specific contributions made by the facilitator and how the teacher team responds to those.

## Practical implications

Based on the current case-oriented analysis, we cannot nor do we aim to make claims regarding what is effective interaction in general, since what works is highly situational and practices and norms are complex and interdependent (see Lefstein et al., 2020). Rather, the aim was to see if we could find contrasts in interaction patterns that could relate back to teachers' self-evaluations of their professional learning gains, so that future research can build on these findings to further our understanding regarding patterns that are more generally connected to teacher learning. If these future studies support our findings, this may result in several practical implications.

First, teachers reported more development in the domain of practice, both current and as intended in the future, than in the personal domain (knowledge and beliefs) or the domain of consequences (benefits for students). In terms of Clarke and Hollingsworth (2002) model, limited reflection took place from the domain of practice to these other domains. Therefore, facilitators of future PLCs may be well advised to steer a group of teachers towards this reflection, by asking reflective questions and explicating gained knowledge. Second, in line with prior findings (e.g., Dobie & Anderson, 2015; Horn et al., 2017; Philpott & Oates, 2017), teachers were limitedly inclined to go beyond

informing each other about their experiences, thereby achieving limited amounts of generative teacher discourse associated with knowledge building. Thus, there is a need for facilitators to push teachers to ask questions, to provide opinions and give an argumentation, and to elaborate on suggestions. Third, PLCs in which teachers experienced learning gains in terms of knowledge versus beliefs differed in their moment-to-moment conversational moves patterns. For facilitators, this implies a necessity to act according to the specific learning goals a professional development program, a group of teachers, or individual teachers may have.

## Conclusion

To conclude, the current study supports earlier findings that teachers need to learn the skill of participating in a PLC to become effective in discussing and achieving knowledge building, ultimately resulting in student learning (Bocala, 2015). With increased experience and adequate scaffolding by a facilitator, conversations hopefully grow to become more diverse, more related to knowledge building, and more generative, so that teacher development through PLCs is optimized. Research can further support this by examining individual teacher contributions in context of the interaction, where they get meaning.

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## Declarations

**Conflict of interest** The authors declare no competing interests.

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#### *Current themes of research*

Dr. Hendrickx: social relationships and interactions in education

Dr. Thurlings: collaborative teacher professional development and learning, teachers as designers

Prof. Den Brok: teacher learning and professional development, innovation in higher education, learning environments

#### *Most relevant publications*

Hendrickx, M., Thurlings, M., & Brok, P. D. (2020). *Dynamic quality of teacher interaction in professional learning communities*. In Gresalfi, M. and Horn, I. S. (Eds.), *The Interdisciplinarity of the Learning Sciences*, proceedings of the 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 4 (pp. 2375–2376). Nashville, Tennessee: International Society of the Learning Sciences.

Hendrickx, M. M. H. G., Mainhard, M. T., Boor-Klip, H. J., Cillessen, A. H. N., & Brekelmans, M. (2016). Social dynamics in the classroom: Teacher support and conflict and the peer ecology. *Teaching and Teacher Education*, *53*, 30–40.

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