

# Automated Linguistic Analysis as a Lens for Analysis of Group Learning

Iris Howley<sup>b</sup> and Carolyn Penstein Rosé<sup>a,b</sup>, Language Technologies Institute<sup>a</sup> and Human-Computer Interaction Institute<sup>b</sup>, Carnegie Mellon University 5000 Forbes Avenue Pittsburgh, PA 15213, {iris,cprose}@cs.cmu.edu

**Abstract.** The multifaceted nature of collaborative learning environments necessitates theory to investigate the cognitive, motivational, and relational dimensions of collaboration. Several existing frameworks include aspects related to each of these three. This article explores the capability of multi-dimensional frameworks for analysis of collaborative processes to isolate and make assessments of these separate dimensions of collaboration. And much work has been done towards computational modeling for automated collaborative process analysis in the past decade. However, while multiple successes of computationalization have been reported in the literature, in this paper we explore the extent to which evidence points to an intertwining between dimensions that calls into questions assessments that can be made based on the observation of codes as they are applied to collaborative discourse. We conclude with a research agenda for future research to address this limitation.

## Introduction

Language behavior is incredibly rich. When used within a protocol analysis methodology, it can be a window into the inner workings of one's mind (Van Someren et al., 1994). When situated within a sense making task, it can provide the opportunity for an individual to externalize that process so it can be inspected (Chi, 1997). Within a social setting, it provides a currency for social exchange as well as visible evidence of otherwise intangible social values and the processes through which they are exchanged (Bourdieu, 1991). In this paper, we are concerned with the latter situation, where language is the visible multi-dimensional manifestation of interaction between individuals, with social, motivational, and cognitive aspects.

In recent years there has been a growing interest in assessment of collaboration (cite PISA collab), and in particular, assessment of collaborative processes visible through discussion (cite Weinberger & Fischer, Strijbos, etc.). It has been argued that discussion provides one of the best windows into affective and motivational processes (cite d'mello), but it should be acknowledged that it comes with specific challenges as well. The related fields of Educational Data Mining (cite something broad in EDM) and Learning Analytics (cite something broad in Learning Analytics) have demonstrated success at modeling learning relevant processes and even using these models to optimize technological support for learning (wires article, assistance dilemma article). A key foundational component of this work has been a formalization of learning objectives into knowledge components and of identification of relevant learning behaviors that can be observed (KLI paper). Structured problem solving activities provide an ideal context in which to demonstrate the success of such an approach since they afford the opportunity to control the sequencing and timing of opportunities to observe the evidence of acquired skills. Learning takes place both in highly structured and far less structured environments alike, however. One goal of the emerging area of discourse analytics is to measure learning relevant processes as they are revealed through discourse (cite proceedings from workshops). One major challenge, however, is that as the environment becomes less structured, the ability to control the

sequencing and timing of opportunities to make related observations is correspondingly reduced. Furthermore, it is well known that there is a complex interplay between cognitive, social, and motivational variables even in settings involving only a single student. As the scope of the context expands from including a single student to multiple students, this complex interplay becomes still more complex and the ability to control timing and sequencing of the opportunity to observe growth is further reduced. This interplay may sometimes interfere with measurement, for example, when a student declines to perform a skill not due to a lack of ability but due to self-consciousness in a social setting.

Analytic technologies applied to language data have demonstrated a certain level of success at estimation of cognitive, social, and metacognitive constructs from observed language behavior in interactive settings (cite bunches of examples). Nevertheless, there is a growing awareness of the extent to which context specificity of models threatens the predictive accuracy of their application across contexts (). The ability to analyze far larger quantities of data than would be possible by hand in part excuses the limited accuracy of state-of-the-art models. Basic research on development of analytic tools works towards improvement of the accuracy of automated measurements from discourse data (), external validation of these measurements (), and application of measurements to theory building (). From a methodological perspective, however, an important question to ask is: given the acknowledged interplay between cognitive, social, and motivational factors, what accuracy should we expect as an upper bound on what can be achieved, both within settings and across settings? Due to the inherent inability of a computational model to detect precisely where it is failing to generalize to a new data point, it is not possible to answer this question through computational modeling alone.

The purpose of this article is to highlight these questions and challenges and suggest an agenda for addressing them in future research. In order to do that, we use as an exemplar a specific process analysis framework named SouFLé that has been featured in handbook chapters defining the area of Discourse Analytics from multiple research communities including Learning Sciences (), Formal Assessment (), Computer-Supported Collaborative Learning (), Educational Technology (), and Learning Analytics (). We integrate findings from five years of development and application of the SouFLé three dimensional categorical coding scheme, including a cognitive, social, and motivational dimension with the specific purpose of identifying types of interference between dimensions that should be considered when interpreting the results of computational models that make similar measurements. In this work, manual application of definitions of coding categories are used as the basis for computational modeling in order both to identify kinds of examples that are out of scope for automated detection, as well as to identify situations where language data fails to provide the opportunity to observe variables along one or more of the three dimensions. While this analysis does not provide a quantitative upper bound on performance of computational discourse models, it takes an important step in that direction by offering the basis for approaching automated discourse analyses with an appropriate level of skepticism that is the earmark of rigorous empirical work.

In the remainder of the paper we describe the three dimensional SouFLé framework, highlighting progress towards computational modeling of each dimension as well as presenting findings from application studies that illustrate specific, concrete instances of the more general issues raised above. We then discuss conclusions from this integration across studies and propose an agenda for work in the area of Discourse Analytics to address in future work.

## **Souflé: Assessment of Collaborative Learning in Synchronous Communication**

Howley, Mayfield and Rosé (2013) first introduced the SouFLé framework as a linguistic analysis approach for studying small groups. The intention was to define contribution level codes in terms of basic language processes without reference to theoretical constructs that are specific to a particular theory of learning or collaboration, but instead grounded in Linguistics (Martin and Rose, 2003; Martin & White, 2005) and very broadly accepted learning relevant constructs from the Learning Sciences such as Transactivity (Berkowitz & Gibbs, 1997; Teasley, 1997; Suthers, 2006; Resnick, Asterhan, and Clark, 2015). More specifically, the aim was to provide a neutral way of describing collaborative processes that might serve as a boundary object for researchers from different theoretical perspectives within the Learning Sciences. Here we define its Cognitive, Relational, and Motivational dimensions in turn (Strijbos, 2011; Howley, Mayfield, Rosé, & Strijbos, 2013; Howley, Kumar, Mayfield, Dyke, & Rosé, 2013). The Cognitive dimension is the one that is most closely connected with learning processes (Berkowitz & Gibbs, 1997; Weinberger & Fischer, 2006). It is designed to identify contributions that can be considered sign posts for sociocognitive conflict. The other two dimensions are meant to trace social positioning processes within conversation that move learners in and out of an appropriate social proximity to one another for the purpose of facilitating engagement in the valued sociocognitive processes highlighted by the Cognitive dimension.

### Example Analysis

We illustrate the three dimensions of SouFLé using an example discussion from a collaborative design task in an undergraduate Thermodynamics course. Codes for each of the three dimensions are indicated, but not defined until the sections that follow. Reading through the example in Table 1, we will see that all three dimensions point to a shift in positioning of the speakers in the conversation in the second half. A tutorial dialogue agent acts as a facilitator in the discussion. The agent, referred to as Dr. Bob, begins as the authoritative source of knowledge, but near the end of the dialogue, student sa08 and sa04 have begun to position themselves as more authoritative sources of the knowledge, as can be seen in the Negotiation dimension, which is used to compute an Authoritativeness score for each student. Likewise along the Engagement dimension, used to measure the communicated openness to other perspectives in the framing of assertions, the initial discussion consists of contributions that on the relational dimension would be coded mostly as given, and thus not up for negotiation. We will refer to this style of assertion as Monoglossic. As the students begin to position themselves more authoritatively, they also acknowledge the possibilities for other views of the knowledge they share, which we will refer to as Heteroglossic in contrast. Just as the students' behavior shifts along these two dimensions, they also begin displaying more reasoning and building on previously contributed ideas. These are the two requirements that define what are called Transactive contributions. Each of the three dimensions of SouFLé is designed to probe a separate dimension of collaborative learning, however, as we discuss below, our finding is that these threads are not so easily disentangled. In this example, we thus observe shifts in the social positioning that are conducive to productive exchange in the cognitive dimension.

**Table 1. A sample dialogue between two students and an automated tutor (Doctor Bob), coded for our three SouFLé dimensions of Negotiation, Engagement, and Transactivity.**

#	Author	Text	Negot	Engage	Transa
1	Dr Bob	Hi - I'm Doctor Bob, your instructor for today's lab.	K1	M-ono	
2	sa04	Well bob, I hope you don't mind that I'm actively hostile to robots.	K1	HE-xpand	
3	Dr Bob	You're working together, but you've each got a different design goal - it's at the top of your worksheet.	K1	M-ono	
4	Dr Bob	Take a moment to share your goal with your partner.	A2		
5	sa08	most environmentally friendly	K1	M-ono	
6	sa04	my goal is to maximize power. yours?	K1/K2	M-ono	
7	Dr Bob	To help you meet your design goals, we are going to discuss some of the parameters given on the worksheet.	K1	M-ono	
8	Dr Bob	Lets start with Tmax.	A1		
9	sa08	so basically, we compromise on greenness and power	A1	M-ono	
10	Dr Bob	The heat rejected by the cycle increases by increasing Tmax.	K1	M-ono	R
11	Dr Bob	We see this in Graph 3 of the worksheet.	K1	HE-xpand	
12	Dr Bob	BTW: Is it safe to keep increasing Tmax?	O		
13	sa08	No	K2	M-ono	
14	sa04	nope. you'll blow out your turbine	K2	M-ono	R
15	Dr Bob	Good. Material properties constrain the maximum temperature we can use in a Cycle. For our cycle, Tmax cannot be more than 570C	K1	M-ono	T
16	Dr Bob	Try using this understanding that our team now shares to come up with a potential value of Tmax (T @ S2) that will help you meet your objectives.	A2		T
17	sa08	We don't want it to be at 570 both for the material and	K1	HE-xpand	T
18	sa08	well, for power and efficiency, we want a high tmax, but environmentally, we want a lower one. It has to be	K1	HE-xpand	T

		higher than 410 for steam quality			
19	sa08	so somewhere between 410 and 570	K1	M-ono	
20	sa08	what about right in the middle, what about 500?	K1	HE-xpand	
21	sa04	seems reasonable	O	HE-xpand	
22	sa08	We choose 500 degrees C	A1	HE-xpand	
23	sa04	however, environmental friendliness can be increased by either increasing efficiency or by reducing waste heat, so maybe it's better to just max out our temperature.	K1	HE-xpand	R

### Modeling Approach

Our approach to automating collaborative process analysis has focused on the development of reliability in our coding schemes to provide training and test sets for supervised machine learning models. In our methodology, we revalidate our coding schemes each time we move on to a significantly different domain or student population. This enables us to notice whether the definitions of codes become less appropriate due to the changes in contextual factors. Then we revalidate and possibly retrain machine learning models. It is well known that predictive models fall prey to over-specificity to the contexts in which the models were trained. A whole area of machine learning research referred to as domain adaptation or multi-domain learning focuses specifically on addressing this problem (), and yet it is far from a solved problem.

This approach is different from some other automated linguistics methods commonly employed to analyze discourse where a set of all purpose scales may be provided based on a specific corpus and then applied to every corpus. Examples include Linguistic Inquiry and Word Count (LIWC) (Chung & Pennebaker, 2014) and Coh-metrix (McNamara et al., 2014).

LIWC analyses a body of text and outputs the degree to which the author expressed a variety of psychological processes, relativity, and personal concerns. Psychological processes commonly include positive and negative emotions, sensory processes, as well as some cognitive (i.e., causation, insight, certainty) and social (i.e., family, friends) processes. Each category includes a collection of words that count towards the sum of that category. For example, positive emotions words include happy, pretty, joy, win, and many more. However, without a more complex linguistic and discourse model, such counts have a tendency to confuse words with more than one meaning. For instance, the word “pretty” may be used both as an adjective, but also as a modifier to an adjective or as an adverb as in “pretty sure” or “pretty bad”. This becomes a larger concern when looking at considerably more informal discourse, such as collaborative learning conversations. Furthermore, while LIWC has a social processes category, the words included are nouns and verbs used to reference communication or people (i.e., mom, coworker, man). Interpersonal communication contains a range of nuanced linguistic behaviors indicating social

positioning and other processes that a bucket for “references to family” will not provide satisfactory insight.

A more sophisticated computational linguistic model might be better suited for the complexity of conversational discourse, and one of such systems is Coh-Metrix. Coh-Metrix is a more theoretically-grounded system which automatically selects and scopes reading materials for students based upon their abilities (McNamara et al., 2014). The system is built upon a multilevel framework to improve student reading through exposure to linguistic features that have been closely associated with deeper comprehension, rather than basic reading comprehension. These five levels include: words (such as parts of speech and word frequency), syntax (via syntactic tree structures), text base (lexical diversity and co-reference), situation model (computed as causal/verb/logical/temporal cohesion), and genre & rhetorical structure (computed as narrativity) (Graesser et al., 2011). The system employs Latent Semantic Analysis, WordNet, and a variety of additional automated linguistic approaches to identify the difficulty of a large corpus of texts.

While multi-faceted tool kits like Coh-Metrix extract linguistic features at a comprehensive set of levels of language representation, it is important to note that it is not comprehensive in terms of the types of linguistic structures that may be relevant for a specific process analysis task on each of those levels, especially at the situation level. While careful application of these train-once approaches (e.g., through hierarchical models that account for variation related to non-independence between data points and systematic variation due to subpopulation variables, guard against some issues with spurious correlations and domain transfer problems discussed above, not all researchers utilizing these tools have applied them in these careful ways. An equally worrisome situation is that validations of the inferences from such frameworks in corpora where they are applied are rarely provided. These are important limitations not in the resources themselves but in how the community of Learning Analytics and related fields have taken them up.

### Cognitive Dimension

The Cognitive dimension of SouFLé is distinct from the other two in that its definition is not strictly linguistic. However, the values underlying the construct of Transactivity (Berkowitz & Gibbs, 1979) are not controversial.

### *Operationalization*

The simple idea behind the concept of Transactivity is a value placed on making reasoning explicit and elaborating expressed reasoning by building on or evaluating instances of expressed reasoning that came earlier in the discussion. The unit of analysis we have adopted in SouFLé was first established for analysis of a related construct referred to as Social Modes of Co-construction (Weinberger & Fischer, 2006). In particular, one unit is the minimal amount of text required to express reasoning, which Weinberger and Fischer refer to as an “epistemic unit”. In their formulation, this is enough text to express a connection between some detail from the given task (which in their case is the object of the case study analyses their students are producing in their studies) with a theoretical concept (which comes from the attribution theory framework, which the students are applying to the case studies). When they have seen enough text that they can see in it mention of a case study detail, a theoretical concept, and a connection between the

two, they place a segment boundary. The simple way of thinking about what constitutes a reasoning display is that it has to communicate an expression of some causal mechanism or express an evaluation or comparison. The basic premise was that a reasoning statement should reflect the process of drawing an inference or conclusion through the use of reason.

Statements that display reasoning can be coded as either Externalizations, which represent a new direction in the conversation, not building on prior contributions, or Transactive contributions, which operate on or build on prior contributions. In our distinction between Externalizations and Transactive contributions, we have attempted to take an intuitive approach by determining whether a contribution refers linguistically in some way to a prior statement, such as through the use of a pronoun or deictic expression.

### *Computational Modeling*

In our prior work, we have developed and applied machine learning techniques for automatic analysis of Transactivity in discussion forums (Rosé, Wang, Cui, Arguello, Stegmann, Weinberger, Fischer, 2008), chat transcripts (Joshi & Rosé, 2007), transcribed group discussions (Ai, Sionti, Wang, & Rosé, 2010), and speech recordings of dyadic discussions (Gweon, Jain, McDonogh, Raj, & Rosé, 2013). When we attempt to build computational models of this and other dimensions, we learn from inspecting the models we build from our data, and those insights contribute back to our understanding of the constructs themselves.

A running theme across computational modeling efforts related to Transactivity across multiple channels of data is that features computed to measure commonality between a contribution and those of different speakers contributed earlier in the conversation improve predictive accuracy. This is not surprising given that the definition of Transactivity refers to integration of or connection between the ideas of different speakers. What this means, though, is that approaches that attempt to predict whether a contribution is transactive or not that extract features for prediction only from the contribution itself, without reference to the context, will be less successful than those that leverage context. A simple way of applying the idea is to include one or more features that represent evidence of connection between a turn and earlier turns by other speakers, such as a measure of lexical cohesion between the current turn and previous turns for different speakers in the same thread (Rosé et al., 2008).

Another way of leveraging interconnectedness between the turns of speakers is to monitor a specific sociolinguistic process in a discussion that suggests an effort to make such connections. Here we use as our example an effort to model speech style accommodation using unsupervised Dynamic Bayesian Networks (Jain et al., 2012) as one step towards automating analysis of Transactivity in speech (Gweon et al., 2012; Gweon et al., 2013). By examining speech style accommodation as a social cue, we can better determine if conversational participants are working to build common ground with one another, which should also be reflected in the prevalence of Transactive statements building on others' ideas (Gweon et al., 2013). Indeed, our work has shown that our automatic measures of speech style accommodation are significantly positively correlated with other-oriented transactive statements.

The concept of Transactivity originally grows out of a Piagetian theory of learning where this conversational behavior is said to reflect a balance of perceived power within an interaction. Earlier research in the area of speech style accommodation suggests that it should be possible to

find evidence of power differentials as well as adjustments in these differentials through shifts in language usage patterns. It can be expected, then, that linguistic accommodation would predict the occurrence of Transactivity, and therefore a representation for language that represents evidence of such language usage shifts should be useful for predicting occurrences of Transactivity. This hypothesis has been confirmed through a demonstration that speech style accommodation as measured by the Jain et al. unsupervised model has a significant positive correlation with prevalence of Transactive contributions in debates between undergraduate students discussing reasons for the fall of the Ottoman empire ( $R = .4$ ) (Gweon et al., 2012). This positive correlation is on the one hand interesting and useful from the standpoint of automated assessment. However, it comes with the troubling side-effect that we must acknowledge that if the prevalence of observed transactivity is influenced through social factors, then we cannot rely on our observation of its occurrence in interaction as a veridical assessment of ability to produce that form of argumentation. Students may be fully capable of the reasoning and articulation skills required to produce transactive contributions and may simply refrain from doing so because of the social environment.

### *Findings*

As expected from prior work, our operationalization of Transactivity has external validity in connection with learning. Our work on analysis of Transactivity in connection with learning is consistent with prior work (Joshi & Rosé, 2007; Teasly, 1997). Beyond its usual role as a mediating variable related to socio-cognitive conflict and learning, in a lab study representing an assembly line task we have confirmed that it is also associated with effective knowledge sharing when newcomers join a new working group (Gweon et al., 2011). Nevertheless, as acknowledged above, we see evidence of the intertwining of cognitive and social factors here. In the example above, social positioning was associated with a conducive environment for Transactivity, by below we will see cases where the opposite is the case.

### The Motivational Dimension

The Motivational dimension in SouFLé is meant to capture conversational behavior that reflects the self-efficacy of students related to their ability to participate meaningfully in the collaborative learning interaction (Howley, Mayfield, & Rosé, 2011).

### *Operationalization*

This dimension, which we have referred to as the Negotiation Framework, is rooted in Martin's Negotiation Framework (Martin & Rose, 2003), from the systemic functional linguistics community. We use codings at this level to compute a relative Authoritativeness score for students within an interaction. Because of this, we sometimes refer to this as the Authoritativeness framework.

This framework highlights the moves that are made in a dialogue as they reflect the authoritativeness with which those moves were made, and gives structure to exchanges back and forth between participants. Our formulation of the Authoritativeness framework is comprised of two axes with six and three codes, respectively, and incorporates structural and pragmatic knowledge of language. At its core for flows of knowledge are two moves in particular. The first is K1, or 'primary knower', and the second is K2, or 'secondary knower'. A 'primary knower'



move includes a statement of fact, an opinion, or an answer to a factual question, such as 'yes' or 'no'. It only counts as 'primary knower' if it is not presented in such a way as to elicit an evaluation from another participant in the discussion. Conversely, a 'secondary knower' move includes statements where the speaker is not positioned as authoritative on the topic at hand, such as asking a question eliciting information, or presenting information in a context where evaluation is the expected response or formulated to elicit feedback. In flows of action, there are corresponding moves of A1, or 'primary actor', and A2, or 'secondary actor'.

There is no strict form-function relationship between these codes and the text being analyzed. The simplest example of this is a line such as 'yeah', which could be authoritative in response to a question or could be non-authoritative response to someone else's evaluation. Additionally, factual statements where the speaker is uncertain of their correctness and is looking for approval from a listener would be coded as a K2 move, even though it is structurally similar to most K1 moves. The roles that speakers take through these codes can shift rapidly within a conversation, and are dynamic, being heavily based on the context of what has happened leading up to an utterance, and how that utterance is responded to by other participants.

When the Negotiation framework is applied to a corpus, each turn gets one code. Sequences of codes form flows of information or action within an interaction. Each complete flow contains exactly one primary core move and at most one secondary core move. Other preparatory and follow up moves may be included. To compute an Authoritativeness score for a student within an interaction, we first count the number of flows that student participated in. When the proportion of such flows in which that student contributed the primary core move, which positions them as the source within that flow. That proportion is the student's Authoritativeness score.

### *Computational Modeling*

Application of this dimension has been automated in chat (Howley et al., 2012), transcribed doctor-patient interactions (Mayfield, Laws, Wilson, & Rosé, 2014), and transcribed collaborative discussions (Mayfield & Rosé, 2011).

In our computational work (Mayfield & Rosé, 2011), we draw insights from the theoretical foundation for the coding scheme that imposes sequencing constraints on patterns of codes within an interaction. While the codes are assigned to individual contributions in a conversation, we are able to encode the sequencing constraints within an Integer Linear Programming framework. The best performing model included these constraints imported directly from the theory foundation for the coding scheme, and significantly outperformed an otherwise equivalent model without the constraints. The model achieved high correlation with Authoritativeness ratings from human assigned codes in a corpus of direction giving dialogues ( $R = .97$ ) as well as a corpus of doctor-patient interactions ( $R = .96$ ). Work on automation of this coding scheme has been one of our strongest demonstrations of the application of insights from linguistics for computational modeling at the discourse level.

### *Findings*

In our prior work we have seen correlations between self-report measures of collective self-efficacy from collaborative groups and measures of authoritativeness of stance derived from our

coding in this dimension (Howley, Adamson, Dyke, Mayfield, Beuth, & Rosé, 2012). In short, on this dimension we consider that an authoritative presentation of knowledge is one that is presented without seeking external validation for that knowledge.

One of our long time such efforts has been using our Negotiation coding as a way of estimating self-efficacy (Howley et al., 2011). We have already described how we are able to use our Negotiation coding to assign an Authoritativeness measure to students by counting the number of flows of information or action within an interaction in which they are positioned as the sources. This enables us to reduce the turn by turn coding into a scale. In reducing the pattern of codes to a scale, we are then able to examine the extent to which this positioning on the vertical social dimension correlates with extra-linguistic variables. We initially expected to see positive correlations between Authoritativeness and extra-linguistic variables that are associated with a value placed on capability in connection with the specific knowledge and action associated with the threads used in the computation. Our initial interpretation suggested we could leverage Authoritativeness as a potential behavioral measure of academic self-efficacy. However, application of the same coding scheme to data in strikingly different contexts challenges an overly simplistic interpretation of the significance of the Authoritativeness rating.

For example, Authoritativeness correlates both with domain related academic self-efficacy and learning in collaborative problem solving settings (Howley et al., 2011; Howley et al., 2012). This relationship is reasonable since the ability to provide knowledge and act in task relevant ways is what academic self-efficacy measures in these contexts, and the tasks are designed in such a way that meaningful task engagement is meant to produce learning. What is even more interesting is that it also sheds light on the interplay between social and cognitive factors in learning, and points to opportunities for impacting engagement in important learning behaviors by addressing social problems such as bullying (Cui et al., 2008; Howley et al., 2012). In this work, we saw that students respond to aggressive behavior by reducing their level of authoritativeness in an interaction, which at the extreme end of the spectrum resulted in a reduction of learning relevant responses to impasses in problem solving, and ultimately a reduction in learning. While it would be possible to explain this reduction in learning through a purely cognitive explanation, exploring the situation more broadly in terms of both social and cognitive factors, we see the reduction in learning relevant behaviors from a cognitive perspective had a social cause. In this context, Authoritativeness is a reflection of a student's estimation of their ability to contribute to the joint problem solving. In the absence of such confidence, a student would reasonably abdicate to the other student deemed more capable. This anticipated correlation between Authoritativeness and self-efficacy appears in additional work (Howley et al., 2011; Howley et al., 2012).

It is consistent with this interpretation to expect different correlations in contexts where the expectations associated with task roles are different, such as in doctor-patient interactions where the doctor is expected to have special knowledge not possessed by the patient. As an evaluation of the predictive validity of our Authoritativeness metric in a health context, in the past year we have applied the Authoritativeness metric to analysis of doctor-patient communication (Mayfield et al., 2013). We measured the predictive validity of this metric in connection with validated measures related to trust in doctor-patient communication. In particular, we tested 5 specific trust related constructs selected by colleagues at Brown University who specialize in trust in doctor-patient communication. We determined that over a corpus of 450 doctor-patient

interactions paired with questionnaire data, 4 out of 5 constructs were significantly correlated with Authoritativeness, with R values ranging from .25 to .35 using Authoritativeness scores that were computed from hand coded Negotiation codes. A construct related to patient health efficacy from the same questionnaire data did not correlate with patient Authoritativeness, which is expected in this context since the role of patient comes with different expectations with respect to expertise than a collaborative problem solving session.

In addition to providing the basis for the Authoritativeness scale, the Negotiation codes more generally have been valuable for structuring multi-threaded conversational interactions in preparation for subsequent analysis. For example, analysis of task relevant differences in information sharing practices between military and civilian pairs performing the same task in a lab study (Mayfield et al., 2012b) as well as conversational strategies associated with stress reduction in online cancer support chats (Mayfield et al., 2012a; Mayfield et al., 2012c). There we have also found that positioning with respect to knowledge transfer is predictive of stress reduction in these chats, however it does not appear to be directly related to self-efficacy. In particular, a closely related notion is Empowerment, which we have found is related to aspects of our Negotiation coding, but not the summative Authoritativeness ratio.

As the connection between Authoritativeness and external variables in different domains plays out differently, we realize our original conception of the Negotiation codes as representing a Motivational dimension related to self-efficacy was too simplistic. Across all of the contexts, we see an explanation for its significance in terms of positioning for active contribution. But the implications of that contribution in terms of what it presupposes from the speakers and how it affects them and others appears to be quite context dependent. In our more recent work we have characterized it more directly in terms of knowledge transfer (Mayfield et al., 2013). However, we cannot deny that within a learning context, the ability, opportunity, and success at contributing knowledge actively within an interaction has tremendous significance in terms of self-efficacy, and other constructs related to self-esteem and engagement. Here we begin to see the lines between cognitive and motivational dimensions begin to blur.

## **Towards Disentanglement**

What we learn from this is that although we typically think of Transactivity from a Cognitive perspective, at a deep level, it has social implications. Authoritativeness is not just a reflection of the impetus to contribute to a conversation, but also a reflection of a particular quantity of knowledge for which a person is willing to take responsibility. Finally, to round out this picture, we are reminded that the relational dimension of SouFLé has as its strongest result its correlation with contribution of reasoning and ideas in interactions. We must conclude that while our initial goal was to separate the cognitive, motivational, and relational dimensions of collaboration for our verbalization theory, our work on computational modeling shows us how strongly intertwined these dimensions actually are.

Outside of collaborative learning linguistic analyses, there is ample evidence that the cognitive, motivational, and social dimensions of learning are intertwined as well. Baker et al. (2010) showed that student affect in individual learning situations had an impact on cognitive outcomes. That is, boredom and especially persistent boredom was associated with poorer learning and more off-task behavior. So, even in an individual interactive learning environment, the affective and cognitive threads are intertwined. Joksimovic et al. (2013) looked at the relationship of

cognitive processes and language in a collaborative learning environment and discovered a similar intertwining. Their results showed that different phases of Communities of Inquiry cognitive presence (i.e., triggering, exploration, integration, and resolution) are associated with different words reflective of different thinking depths. Words of interest were determined based upon the LIWC categories such as causal (e.g., because, hence) and insight (e.g., consider, think, know) words, among others.

While our SouFLé analyses has shown us that the cognitive, motivational, and social processes are intertwined, prohibiting a simple path to achieving a verbalization theory, our framework has also shown its strength as a mid-level lens from which to better understand key moments in the collaborative learning process. The first step when working with a new microscope is to adjust the height of the lens above the specimen of interest. An ideal environment in which to engage in such an effort is in the midst of a multivocal analysis where researchers who are steeped in alternative methodologies each analyze the same dataset using their own approach, and then challenge one another's assumptions and interpretations. We have had the valuable opportunity to see what SouFLé is able to elucidate in comparison with two alternative approaches, one much higher level (a social network analysis) and one much more detailed (a qualitative analysis) on two different data sets as part of a large scale investigation into multivocality as a new approach for analysis of collaborative learning (Suthers, Lund, Rosé, Teplov, & Law, 2013). In connection with one of these data sets, we also had the opportunity to contrast SouFLé with an alternative three dimensional analysis scheme.

In the first of the two data sets (Rosé, 2013a; Hmelo-Silver, 2013), four different analytic teams analyzed data from a study where 9<sup>th</sup> grade biology students worked on a virtual lab related to diffusion (Dyke et al., 2013). There were two qualitative analyses, a network analytic approach, and our own SouFLé analysis. In this set of analyses, both one of the qualitative analyses (Stahl, 2013) and the network analytic approach (Goggins & Dyke, 2013) adopted a network-like representation. Another qualitative analysis (Cress & Kimmerle, 2013) took a purely descriptive approach. The issue of social positioning was the focus of the SouFLé (Howley et al., 2013b) analysis as well as one qualitative analysis (Stahl, 2013), and the network approach (Goggins & Dyke, 2013; Stahl, 2013). The main contrast was in terms of the focus of inquiry. Both the qualitative and network analytic analyses focused on the relative level of dominance of the participants within groups. At their alternative ends of a spectrum of zooming out and zooming in, the high level network analytic approach was able to provide a summative view of the interactions, where it was clear in the end which participant within each group had communicated the most. At the other end of the spectrum, the qualitative approach was able to provide snapshots of behavior where domineering or dominating behavior was vividly illustrated. Interestingly, the coding and counting approach of the SouFLé analysis was able to represent the pattern of behavior over time. Showing the different aspects of behavior overtime set the behaviors identified as domineering in the other analyses into a different context. This process analysis eventually pinpointed aspects of the intervention that triggered a ripple effect of negativity within groups that was different from the behavior either of the other analyses brought out as potentially problematic. Thus, SouFLé provided something of a sweet spot for challenging assumptions and interpretations.

In the second of the two data sets (Rosé, 2013b; Rosé, 2013c), groups of undergraduates worked together on chemistry problems (Sawyer, Frey, & Brown, 2013a). In this data set, the SouFLé

analysis (Howley et al., 2013c) was contrasted both with an alternative three dimensional coding and counting approach in addition to being compared with a network analytic approach (Oshima, Matsuzawa, Oshima, Nihara, 2013) and a qualitative approach (Sawyer, Frey, & Brown, 2013b). In this case, again, both the network analytic approach and the qualitative approach focused on similar issues, namely the contrast between a team thought to take a more conceptual approach and another team that took what appeared to be a more procedural approach. All analyses touched upon the issue of leadership within teams.

Similar to the experience with the first dataset, the coding and counting approaches challenged the interpretation of both the more abstract and less abstract approaches. In particular, the formalization of contributions to the conversation at the cognitive level offered the opportunity to ask what it meant for the two groups to approach the content conceptually versus procedurally. The end result was a perspective that revealed both groups engaging in a mixture of both of these foci, and in some ways the biggest difference was in the way they approached these two foci rather than an actual difference in emphasis. Similarly, the two coding and counting approaches were able to pinpoint different aspects of leadership within teams that might be relative strengths and weaknesses of different students within groups. As in the earlier set of analyses, the unique contribution of the coding and counting approaches was the extent to which they enabled viewing the nature of the collaborative process as it unfolded over time. The network approach was very adept at providing a summative view of contribution at various points in time. The qualitative approach was able to provide a blow by blow story describing the contrasting groups and punctuating the story with vivid images from raw data snippets. The coding and counting approaches were able to illustrate the complexity of the construct of leadership and contribution within collaborative groups.

A contrasting impression came from comparing across approaches when pinpointing pivotal moments in the collaboration. In the network analysis, a moment was called out as pivotal because a change took place in the shape of the evolving network after that time. In the coding and counting approaches, pivotal moments were called out because something in the form or content of a contribution itself was striking based on the formal definitions of the codes. In the qualitative analysis moments were called out as pivotal if they struck the analyst as pivotal apart from any pre-conceived definitions. From this standpoint, we are challenged to think about ways in which all of these approaches might be wielded more flexibly to either provide a summative or process oriented perspective.

An especially interesting contrast came out in the comparison between the two coding and counting approaches, one being the SouFLé framework and the other a three dimensional framework by Strijbos (Rosé, 2013c). Here we see some evidence of the value of a linguistic approach in making fine-grained distinctions in terms of the social significance of language choices. In particular, when comparing the relational dimensions of the two coding schemes, we see value in the linguistic formulation of Engagement where we are able to represent more of the subtlety in how openness or closedness is communicated in language. In particular, we saw the subtleties behind the idea of dominance and the different ways that positive versus negative may be viewed. In the SouFLé framework, contributions are characterized as expanding or contracting the set of ideas that remain up for consideration. In the Strijbos framework (Strijbos, 2011), contributions are characterized as either enacting a positive or negative polarity. In our comparison we saw that there is a many-to-many correspondence between these distinctions.

Within both frameworks, one is viewed as more imposing (contracting, negative) and the other less imposing (expanding, positive). Because of the many-to-many correspondence, it is possible (and indeed happens!) that a participant may be rated as more dominant than another student in one coding scheme and the reverse in the other. The SouFLé framework characterizes the way a negative phrasing can be used to remove a hindrance to consideration of an idea. Thus, a negative phrasing does not necessarily communicate lack of openness towards group members, although it necessarily shows a lack of openness towards something. However, in terms of the relationship between speakers, it is not necessarily imposing. The subtlety with which SFL approaches the many layers of language choices that are encoded in each framing of an assertion within interaction proves its value here where we value the ability to monitor the effect of the framing of contributions on the social positioning of speakers with respect to one another in a discussion.

Overall what we conclude is that SouFLé is most valuable in terms of visualizing a process over time, especially in terms of teasing out specific details of linguistic choices and their implications on the tenor of an interaction, as well as illustrating the interplay between cognitive, relational, and motivational dimensions of collaboration. It may be less adept than a network analytic approach at providing a bird's eye view of the summative effects of behaviors that occur over time or of providing a detailed snap shot of specific behaviors that might stand out as striking to a human analyst.

### The Relational Dimension

The Relational dimension in Souflé is meant to capture the level of openness to the ideas of others that is communicated in a student's framing of assertions.

#### *Operationalization*

Whereas in the Cognitive dimension we adopted an approach in which we identify expressions of reasoning and Transactivity, in the Relational dimension, we base our work on the earlier Systemic Functional Linguistic (SFL) work of Martin and White (2005), whose theoretical approach explicitly mandates not going beyond the evidence that is explicit in a text. The important distinction in our application of the Martin and White's Heteroglossia framework is the distinction between a monoglossic assertion, that is framed as though it leaves no room for questioning, in contrast to those framed in a heteroglossic manner, where the assumed perspective of others is explicitly acknowledged within the framing. There are two types of contributions we code as Heteroglossic, one type that shows openness to other perspectives, which we refer to as Heteroglossic Expand, and another that explicitly expresses a rejection of some other perspective, which we refer to as Heteroglossic Contract.

#### *Computational Modeling and Findings*

In our published work we have analyzed Heteroglossia in interaction analysis by hand, but not automatically. In that study we found a significant and strong correlation between displayed openness in a discussion group and the prevalence of reasoning displays (). In our computational work related to this dimension, we implemented a conversational computer agent such that we manipulated the style, in one condition as Heteroglossic Expand, and in another condition as Heteroglossic Contract. In the Expand condition we observed significantly more inclination to

make ideas explicit (cit). This again highlights the importance of the intertwining of dimensions for the purpose of assessment. In this case, we see how social factors affect our ability to observe a student's ideation in a discussion context.

## **Conclusions and Current Work**

In this paper we have described work to date related to operationalization and computationalization of a multi-dimensional framework for collaborative process analysis. We have motivated our methodological approach, operationalized each dimension, described successes where they have been achieved on automated analysis, and summarized findings. An important theme is the intertwining of cognitive, social, and motivational variables as observed in interaction.

We began this reflection by discussing the ways in which forms of analysis of learner discourse may enable us to understand more about learning processes and assess collaborative skill. However, let us now stop and reflect on the careful way in which protocol analysis is applied in order to understand thinking, problem solving, and learning processes (Van Someren et al., 1994). There is an accompanying notion of a verbalization theory that stipulates the limitations of the methodology on obtaining a veridical perspective on such processes. Now we reflect on the idea of a verbalization theory as a way of monitoring our ability to see a veridical reflection of the speaker's internal processes in the data we collect and analyze. The role of such a theory is to serve as a caveat of what we need to be careful of when using a lens to answer a scientific question. Since we see how intertwined the Cognitive, Relational, and Motivational dimensions are in collaborative learning, we cannot assume that utterances in our social dialogues are purely reflective of cognitive processes, but rather are a combination of all three dimensions. This highlights the importance of not reducing down to a single dimension, or characterizing problems and solutions on only one dimension. However, we see in this work evidence that including multiple dimensions does not solve the problem either. The dimensions themselves may isolate behaviors specifically related to those dimensions, and yet the distributions of codes on each dimension are related to the distributions of codes on the other dimensions because of the way those dimensions themselves are entangled with one another. The challenge that remains is in moving beyond the caveats towards solving these problems and elucidating new knowledge.

Perhaps the greatest success at isolating a single dimension has come from our work on speech style accommodation. Here the success was in isolating the social dimension of an interaction specifically in very low level linguistic choices at the phoneme level. At this level, the manner of speaking is least influenced by the content of what is spoken. While the social dimension of interaction appears to greatly influence what we are able to view on the cognitive dimension (i.e., social considerations may inhibit display of cognitive abilities and processes), the converse may not be true. Moreover, if the social dimension does indeed turn out to be more basic in this respect, then if we can progress in our attempt to translate linguistic theory about the social implications of language choices into computational models, we may be able to at least identify the places where we can and can't see a faithful representation of what is happening at a cognitive level. This addresses the challenge that computational models in general cannot be depended upon to identify which instances they are not able to classify properly. The valuable insight here is that we may be able to identify those places where social considerations might be obscuring our view on other dimensions. We may never be able to view all that we want to see

in terms of the cognitive processes at work in collaborative settings if this would require removal of social factors. However, as we further elaborate our verbalization theory, we may learn how to better set up the conditions of collaboration in such a way that we are in the best possible position to isolate those aspects of cognition we want to study, and then to interpret what we see properly.

## ACKNOWLEDGMENTS

Special thanks to all of the contributors to this work, including Elijah Mayfield, Gregory Dyke, Rohit Kumar, David Adamson, Gahgene Gweon, Mahaveer Jain, Dong Nguyen, Bhiksha Raj, John Mc Donough, Dan Suthers, Kris Lund, Chris Teplovs, and Nancy Law. This research was supported in part by NSF grant OMA-0836012.

## REFERENCES

- Ai, H., Sionti, M., Wang, Y. C., & Rosé, C. P. (2010). Finding transactive contributions in whole group classroom discussions. In K. Gomez, L. Lyons & J. Radinsky (Eds.), *Proceedings of the International Conference of the Learning Sciences* (pp. 976-983). Chicago, IL: International Society of the Learning Sciences.
- Baker, R. S. J. d., D'Mello, S. K., Rodrigo, M. M. T., & Graesser, A. C. (2010). Better to be frustrated than bored: The incidence, persistence, and impact of learners' cognitive-affective states during interactions with three different computer-based learning environments. *International Journal of Human-Computer Studies*, 68(4), 223–241.  
doi:10.1016/j.ijhcs.2009.12.003
- Berkowitz, M., & Gibbs, J. (1983). Measuring the developmental features of moral discussion. *Merrill-Palmer Quarterly*, 29, 399–410.
- Bourdieu, P. (1991). *Language and Symbolic Power*, Harvard University Press.
- Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *The Journal of the Learning Sciences*, 6(3), 271-315.
- Cui, Y., Chaudhuri, S., Kumar, R., Gweon, G., Rosé, C. P. (2009). Helping Agents in VMT, in G. Stahl (Ed.) *Studying Virtual Math Teams*, Springer CSCL Series, Springer.
- Chung, C. K., & Pennebaker, J. W. (2014). Using Computerized Text Analysis to Track Social Processes. In T. Holtgraves (Ed.), *Oxford Handbooks Online*. Oxford.
- De Wever, B., Schellens, T., Valcke, M., & Van Keer, H. (2006). Content analysis schemes to analyze transcripts of online asynchronous discussion groups: A review. *Computers and Education*, 46, 6–28.
- Dyke, G., Howley, I., Adamson, D., Kumar, R., Rosé, C. P. (2013). Towards Academically Productive Talk Supported by Conversational Agents, in Suthers, D., Lund, K., Rosé, C. P., Teplovs, C., Law, N. (Eds.). *Productive Multivocality in the Analysis of Group Interactions*, edited volume, Springer.



- Dyke, G., Adamson, A., Howley, I., & Rosé, C. P. (2013). Enhancing Scientific Reasoning and Discussion with Conversational Agents, *IEEE Transactions on Learning Technologies* 6(3), special issue on Science Teaching, pp 240-247.
- Graesser, A. C., & McNamara, D. S. (2011). Computational Analyses of Multilevel Discourse Comprehension. *Topics in Cognitive Science*, 3(2), 371–398. doi:10.1111/j.1756-8765.2010.01081.x
- Gweon, G., Rosé, C. P., Zaiss, Z., & Carey, R. (2006). Providing support for adaptive scripting in an on-line collaborative learning environment. *CHI 06: ACM conference on human factors in computer systems*.
- Gweon, G., Jain, M., Mc Donough, J., Raj, B., Rosé, C. P. (2013). Measuring Prevalence of Other-Oriented Transactive Contributions Using an Automated Measure of Speech Style Accommodation, *International Journal of Computer Supported Collaborative Learning* 8(2), pp 245-265.
- Gweon, G., Jain, M., McDonogh, J., Raj, B., Rosé, C. P. (2012). Predicting Idea Co-Construction in Speech Data using Insights from Sociolinguistics, in *Proceedings of the International Conference of the Learning Sciences*, Sydney, Australia.
- Howley, I., Mayfield, E., Rosé, C. P. (2011). Missing Something? Authority in Collaborative Learning, in *Proceedings of Computer Supported Collaborative Learning*
- Howley, I., Adamson, D., Dyke, G., Mayfield, E., Beuth, J., & Rosé, C. P. (2012). Group Composition and Intelligent Dialogue Tutors for Impacting Students' Self-Efficacy, *ITS 2012 Proceedings of the 11<sup>th</sup> International conference on Intelligent Tutoring Systems*, Lecture Notes in Computer Science Volume 7315, Springer-Verlag, pp 551-556.
- Howley, I., Kumar, R., Mayfield, E., Dyke, G., & Rosé, C. P. (2013a). Gaining Insights from Sociolinguistic Style Analysis for Redesign of Conversational Agent Based Support for Collaborative Learning, in Suthers, D., Lund, K., Rosé, C. P., Teplov, C., Law, N. (Eds.). *Productive Multivocality in the Analysis of Group Interactions*, edited volume, Springer.
- Howley, I., Mayfield, E., Rosé, C. P., Strijbos, J. W. (2013b). A Multivocal Process Analysis of Social Positioning in Study Groups, in Suthers, D., Lund, K., Rosé, C. P., Teplov, C., Law, N. (Eds.). *Productive Multivocality in the Analysis of Group Interactions*, edited volume, Springer.
- Howley, I., Mayfield, E. & Rosé, C. P. (2013c). Linguistic Analysis Methods for Studying Small Groups, in Cindy Hmelo-Silver, Angela O'Donnell, Carol Chan, & Clark Chin (Eds.) *International Handbook of Collaborative Learning*, Taylor and Francis, Inc.
- Jain, M., McDonogh, J., Gweon, G., Raj, B., Rosé, C. P. (2012). An Unsupervised Dynamic Bayesian Network Approach to Measuring Speech Style Accommodation, *EACL 2012 Proceedings of the 13<sup>th</sup> Conference of the European Association for Computational Linguistics*, Avignon, France, April 23-27, 2012, pp787-797.
- Joksimovic, S., Gasevic, D., Kovanovic, V., Adesope, O., & Hatala, M. (2014). Psychological characteristics in cognitive presence of communities of inquiry: A linguistic analysis of online discussions. *The Internet and Higher Education*, 22, 1–10. doi:10.1016/j.iheduc.2014.03.001

- Joshi, M., & Rosé, C. P. (2007). Using transactivity in conversation summarization in educational dialog. In Proceedings of the SLaTE Workshop on Speech and Language Technology in Education.
- Martin, J. R., & Rose, D. (2003). Working with Discourse: Meaning Beyond the Clause. Continuum.
- Martin, J. R., & White, P. R. R. (2005). *The language of evaluation: Appraisal in English*. Place: Palgrave/ Macmillan.
- Mayfield, E., & Rosé, C. P. (2011). Recognizing authority in dialogue with an integer linear programming constrained model. In Y. Matsumoto & R. Mihalcea (Eds.), *Proceedings of the 49th Annual Meeting of the Association for Computational Linguistics: Human Language Technologies*. Portland, OR: Association for Computational Linguistics.
- Mayfield, E., Wen, M., Rosé, C. P., Golant, M. (2012). Discovering habits of Effective Online Support Groups, *GROUP '12 Proceedings of the 17th ACM International Conference on Supporting Group Work*, ACM, New York, pp 263-272.
- Mayfield, E., Adamson, D. & Rosé, C. P. (2012). Hierarchical Conversation Structure Prediction in Multi-Party Chat. *Proceedings of the SIGDIAL 2012 Conference, The 13th Annual Meeting of the Special Interest Group on Discourse and Dialogue*, 5-6 July 2012, Seoul National University, Seoul, South Korea. The Association for Computer Linguistics 2012, pp 60-69.
- Mayfield, E., Adamson, D., & Rosé, C. P. (2013). Recognizing Rare Social Phenomena in Conversation: Empowerment Detection in Support Group Chatrooms, *Proceedings of the Association for Computational Linguistics*
- Mayfield, E., Laws, B., Wilson, I., & Rosé, C. P. (2013). Automating Annotation of Information Flow for Analysis of Clinical Conversation, *Journal of the American Medical Informatics Association*.
- McNamara, D. S., Graesser, A. C., McCarthy, P. M., & Cai, Z. (2014). Automated evaluation of text and discourse with Coh-Metrix. Cambridge, M.A.: Cambridge University Press.
- Rosé, C. P., Wang, Y.C., Cui, Y., Arguello, J., Stegmann, K., Weinberger, A., Fischer, F., (2008). Analyzing collaborative learning processes automatically: Exploiting the advances of computational linguistics in computer-supported collaborative learning. *International Journal of Computer Supported Collaborative Learning*, 3(3), 237-271.
- Rosé, C. P. (2013). A Multivocal Analysis of the Emergence of Leadership in Chemistry Study Groups, in Suthers, D., Lund, K., Rosé, C. P., Teplovs, C., Law, N. (Eds.). *Productive Multivocality in the Analysis of Group Interactions*, edited volume, Springer.
- Sawyer, Frey, & Brown (2013). Peer Led Team Learning in General Chemistry. In Suthers, D., Lund, K., Rosé, C. P., Teplovs, C., Law, N. (Eds.). *Productive Multivocality in the Analysis of Group Interactions*, edited volume, Springer.
- Strijbos, J. W. (2011). Assessment of (computer-supported) collaborative learning. *IEEE Transactions on Learning Technologies*, 4(1), 59-73.
- Suthers, D. (2006). Technology affordances for inter-subjective meaning making: A research agenda for CSCL. *International Journal of Computer Supported Collaborative Learning*, 1, pp. 315-337.

- Suthers, D., Lund, K., Rosé, C. P., Teplovs, C., Law, N. (2013). *Productive Multivocality in the Analysis of Group Interactions*, edited volume, Springer.
- Teasley, S. D. (1997). Talking about reasoning: How important is the peer in peer collaboration? In L. B. Resnick, R. Säljö, C. Pontecorvo, & B. Burge (Eds.) *Discourse, tools and reasoning: Essays on situated cognition* (pp. 361–384). Berlin: Springer.
- van der Pol, J., Admiraal, W., & Simons, P. R. J. (2006). The affordance of anchored discussion for the collaborative processing of academic texts. *International Journal of Computer-Supported Collaborative Learning*, 1(3), 339–357.
- van Someren, M. W., Barnard, Y. F., & Sandberg, J. A. C. (1994). *The Think Aloud Method: A Practical Guide to Modeling Cognitive Processes*. New York: Academic Press. Chapter 7
- Veel, R. (2000). Language, knowledge and authority in school mathematics, in Christie, F. (Ed.) *Pedagogy and the Shaping of Consciousness: Linguistic and Social Processes*. Continuum
- Weinberger, A., & Fischer, F. (2006). A framework to analyze argumentative knowledge construction in computer-supported collaborative learning. *Computers & Education*, 46(1), 71–95.