Processes of argumentation and explanation in conceptual change: Results from protocol analyses of peer-to-peer dialogue

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Abstract: Decades of research have proven that many misconceptions of scientific notions are difficult to uproot even after intensive instructional interventions. In this paper we examine the role of argumentation and of explanation development in dyadic dialogues and their relation to consequential individual conceptual change. Two quantitative dialogue coding schemes were developed with different granularity: The first assessed the interlocutors' dialog moves during the discussion that pertained to argumentation and explanation development. The second scheme characterized the dialogue as a whole on a number of social and socio-cognitive dimensions. The results emphasized the critical role of engagement in dialectical argumentation for conceptual change, whereas explanation development and validation was not related to learning gains. This finding may explain why instructional interventions are too often insufficient to uproot robust misconceptions. The methodological implications for the study of conceptual change, as well as the practical implications for designing for productive argumentation are discussed.

Introduction

Research on inducing conceptual change among students has been heavily influenced by Piagetian notions of learning, according to which intra-personal cognitive conflict leads children to seek equilibrium and, hopefully, to accommodate their pre-existing conceptions into new ideas (Piaget, 1985). Piaget, thus, describes a basic learning mechanism. Researchers have attempted to apply these descriptive notions to design learning tasks that are assumed to induce intra-personal conflict among students. Such designs rely on creating conditions in which students' naïve conceptualizations are confronted with anomalous data or contradicting views, and are generally referred to as the *cognitive conflict paradigm* in instruction (e.g., Limon, 2001).

However, results from empirical studies that have applied this paradigm in instructional strategy are, overall, rather disappointing. These type of tasks are cognitively very demanding. For example, Chinn and Brewer (1998) have shown that ignoring, rejecting, excluding, reinterpreting and expressing uncertainty about the validity of anomalous data are common responses among undergraduates. To engage in such tasks, students will need to be highly motivated and engage in, what has been referred to as*, deep processing* (Doyle & Sinatra, 1998).

The cognitive conflict paradigm has also been implemented in peer collaboration settings (*socio-cognitive conflict*) by pairing students with different initial conceptualizations or by presenting collaborators with contradictory information. Theoretically, collaborative tasks seem to be more promising for concept learning within this paradigm than individual settings: According to (neo-)Piagetian theory, the confrontation of different cognitions in combination with the equality in status are considered to induce high levels of cognitive conflict which are thought to be crucial for the occurrence of conceptual change (e.g., Mugny & Doise, 1978). The interaction with an equal-status peer may also promote reflection and awareness to the incompleteness of one's own understanding (Keil, 2006; Limon, 2001) and cause learners to engage in explanatory activities, such as the consideration of alternative ideas (Okada & Simon, 1997). In addition, having (a) partner(s) may reduce the cognitive load as a result of the combination of individual resources and the distribution of task-related cognitive demands among the participants (Dillenbourg, 1999).

However, as the literature on peer collaboration has extensively and repeatedly shown, simply putting two people together is not sufficient (e.g., Coleman, 1998; King & Rosenshine, 1993). Even the creation of heterogeneous groups according to personal beliefs and performance does not ensure productive peer collaboration. An increasingly large body of research seems to indicate that for collaborative task designs to be effective, more than anything else, participants have to actually transact on and engage in each other's ideas (e.g., Chan, Burtis & Bereiter, 1997; Rogoff, 1998).

Recent post-hoc analyses of peer dialogues seemed to suggest that the key to substantive learning gains within the socio-cognitive conflict paradigm may be found in argumentation (Schwarz, Neuman & Biezuner, 2000; Schwarz & Linchevski, 2007). This claim was experimentally tested in a study on conceptual understanding in evolutionary theory in which argumentation was treated as a condition (Asterhan & Schwarz, 2007b): Undergraduates were assigned to dyads and collaboratively tried to explain an evolutionary phenomenon (i.e., the evolution of webbed feet of ducks). Half of the dyads were instructed to engage in argumentative dialogue on their respective explanations and received some written examples of argumentative

moves; the other half was merely instructed to collaborate. When controlled for pretest performance, delayed posttest explanations of students in the argumentative condition were found to testify of better conceptual understanding than those of control students. However, in spite of these mean differences between conditions, not all experimental subjects attained conceptual change and not all experimental dyads engaged in a *dialectical* argumentative discussion, in spite of the instructions and task design. In the present study, we attempt to identify critical features of dyadic dialogues with respect to conceptual change by exploring the factors that distinguish between the dialogues of dyads that achieved substantive conceptual gains and those that did not. Previous findings lead us to focus on the role of argumentative moves within a dialogue.

In addition to argumentation, acts of explanation development were also assessed. The importance of explanatory activities, such as elaboration and the development of scientific explanation, has been proven in a number of research works: for example on activities such as explanatory activities (Okada & Simon, 1997), self-explanation (e.g., Chi, deLeeuw, Chiu, & Lavancher,1994; Coleman, 1998), elaborative talk (van Boxtel, van der Linden & Kanselaar, 2000), and reciprocal questioning (King & Rosenshine, 1993). Even though the operational definitions of some of these activities may have contained some argumentative elements, they all focus on explanation-driven discourse. While in the same dialogue acts of explanation and argumentation often occur interchangeably, they are two quite different epistemic actions that should preferably be distinguished.

The act of explaining, for example, often resembles argumentation, which substantially complicates the process of identification. They are both acts of reasoning and have therefore similar syntactic and formal structures: They are made up of at least two propositions, in which one is presented as the starting point which leads to the other, the end point. In addition, they often make use of similar indicator words, such as 'because', 'therefore', 'as a result of', and 'since'. Moreover, both explanation and argumentation are *verbal* and *social* acts of reasoning. Explanations, like arguments, are of a transactional nature: They have recipients, whether this occurs on the intra-personal plane between two individuals, or on the intra-personal level where an individual explains something to the self. In both cases, the goal of the explanation is to expand the recipient's understanding (Keil, 2006).

In spite of these resemblances, argumentation and explanation differ in at least one important aspect: their purpose. An explanation has a clarifying function within a dialogue, in the sense that the recipient should come to understand something better as a result of the explanation. It is often, but not always, preceded by requests for clarifications. In argumentation, on the other hand, the proponent proposes reasons for the recipient to come to accept a certain thesis (Walton, 2006). Baker (2002a; 2003) defines argumentation as an activity that involves establishing specific types of relations between the propositions being discussed and other sources of knowledge, the establishment of which is meant to influence the epistemic statuses of these propositions. Then the distinction between argumentation and explanation should be made based on the context of the dialogue, both in a local and general sense.

It is imperative to distinguish between processes of argumentation and explanation, since the two testify of different (socio-)cognitive processes each of which may prove to be beneficial in different task designs, different domains and different types of concepts. So as to optimize opportunities for learning, task designs have to be contingent on the type of learning that is required. Within the conceptual change literature, for example, two different mechanisms of conceptual learning have been proposed: There are those misconceptions that require radical knowledge reorganization, whereas others may be repaired by accumulation of additional, but crucial knowledge, a so-called *incremental* change (Chi, et al, 1994; de Leeuw & Chi, 2003; Gentner, Brem, Ferguson, Markman, Levidow, Wolff & Forbus, 1997; Vosniadou & Brewer, 1994). For example, one domain that requires "mere" incremental change is the blood circulation system (Chi, et al, 1994; de Leeuw & Chi, 2003). De Leeuw and Chi (2004) found that asking students to self-explain a text to themselves on the circulatory system lead to incremental changes by replacing one or more false beliefs with the correct piece(s) of knowledge. Whereas such processes of consensual (co-)construction, which are characterized by acts of explanation development and elaboration may indeed promote incremental conceptual change, they may not suffice when a radical reorganization of conceptual knowledge is required (de Leeuw & Chi, 2004). This is the case for misconceptions that are notoriously resistant to change, such as natural selection (Chi, 2005; Ohlsson & Bee, 1992).

So as to distinguish between processes of argumentation and explanation development, a coding scheme was developed to distinguish moves that referred to the epistemic status of an idea (argumentative interlocutory moves) from those that developed ideas (moves that introduced new information to the discussion, such as those that develop or expand on preceding contributions). An additional coding scheme was developed to capture interpersonal and socio-cognitive features of the discussion as a whole that may distinguish between gaining and non-gaining dyads.

Method

Participants

A total of thirty-eight undergraduates from the Social Sciences and Humanities departments were randomly assigned to dyads. The dialogues of three dyads could not be transcribed for technical reasons. The remaining 16 dialogues were transcribed and analyzed.

Procedure

All students participated in the following sequence of activities: (1) Individual pretest to assess prior evolutionary understanding; (2) Instructional intervention: screening of instructional movie excerpt on evolutionary theory; (3) Collaborative intervention during which dyads solved two evolutionary problems, one warming-up and one transfer item; (4) Individual delayed post-test administered a week later. Pre- and posttests were administered to individuals in group format as paper-and-pencil tests and consisted of one warning up item and two target items in open format on different evolutionary phenomena. No differences in item difficulty were found. The dialogs analyzed are those on the transfer item in the interventional stage, according to which subjects were asked to explain the evolution of webbed feet of ducks. All dyads received written instructions to engage in dialectical argumentative dialog on their respective solutions and some examples of argumentative moves within a discussion. They also received a short excerpt of a critical discussion of four turns between two (hypothetical) subjects which, they were told, had participated in the experiment a year earlier. The excerpt was handed to them while they had been working on the target question (the "ducks" question) for at least 30 seconds, so as to allow them to at least articulate their own solutions to the ducks item. They were told that the experimenter 'forgot' to give them the item in time and that they had to read it and try to relate to it in their discussion. The discussion in the excerpt modeled a critical discussion on the ducks item without actually revealing or hinting at the correct solution (see Asterhan & Schwarz, 2007b, for further details).

Coding procedures for conceptual change

Based on and inspired by previous works ten qualitatively different explanatory schemas (Ohlsson, 2002) were identified in students' explanations of evolutionary change. These different schemas were then quantitatively assessed on four different dimensions: Whether evolutionary change was considered at all, whether this change was explained, whether some sort of selection mechanism was used and whether existing intra-species variation was considered. Based on the appearance of each of these four dimensions, the ten qualitatively different explanatory schemas were assigned to one of five different categories. The score for each schema category was based on the number of dimensions that featured in the schema in that category. An additional null-category was added to distinguish between explanations that did not consider evolutionary change (the lowest category) and those responses that simply did not answer the question at all (by stating that they did not know the answer or by repeating the data given in the item without providing additional information). This procedure thus yielded six explanatory schema categories with scores ranging between 0-5 (see Asterhan & Schwarz, 2007b, for more details).

Based on this classification scheme the operational definition of what would be considered conceptual change in evolutionary theory was defined, and what would account for a "mere" amelioration of existing understanding: Whereas the generative schemata that underlie two explanatory schemas from the same category are qualitatively different, one cannot be considered superior to the other. An intra-categorical shift from one schema to another would, thus, not account for conceptual change. We therefore argue that only shifts from one explanatory schema category to another involve the substantive re-organization that is described in conceptual change theory and research. However, previous research has shown that students' responses to different test items are often not consistent in the explanatory schemas they applied on a given test occasion. Asterhan & Schwarz (2007a) found that more than a quarter of undergraduates were inconsistent in their use of explanatory schemas on the same test. A definition of conceptual change has to take this instability into account. Whereas a student who applied an explanatory schema of a one-point higher category on only one of the two test items (i.e., a mean pre- to delayed post-test increase of .5 points) has indeed shown improved conceptual understanding, we argue that this does not provide *sufficient proof* for a substantive change. Sufficient proof for a more profound reorganization in conceptual understanding, i.e. *radical* conceptual change (DeLeeuw & Chi, 2003), was therefore defined as an increase of at least one point from the mean pre-test to mean post-test score.

Coding procedures of dialogues

The emphasis of the protocol transcription was accuracy of verbal content and sequence of turns, rather than other discourse properties. Turns were parsed based on speaker-continuous speech. When a speaker was interrupted but continued talking, then all the content was considered one turn, and the interruption as another. If an interruption caused the speaker to stop from speaking and pick it up later on, then the resumed content was considered an additional turn. Two complementary coding schemes were developed with different granularity: The first focused on the identification of dialogical moves (micro-level), whereas the goal of the second was to characterize the nature of the interaction as a whole on a number of dimensions (macro-level). The coding

schemes were developed according to a procedure similar to the verbal analysis method described by Chi (1997).

Micro-level assessment scheme: Dialogical moves.

The unit of analysis in this coding scheme is what we refer to as a *dialogue unit*[1]. Maximally, these consist of a complete speaker turn. It is not uncommon, however, for a speaker turn to contain different statements that refer to different topics or have different interlocutory intentions. For this reason a turn may be subdivided in different units, based on pragmatic features, that is: when one turn contains more than one of the dialogical moves described below. Thus, segmentation within a turn is in many ways also the product of the coding scheme application. When a dialogue unit is interrupted by the other speaker but immediately picked up again, it will be considered a continuation of the same dialogue unit.

The scheme comprises a number of non-exhaustive, but mutually exclusive categories that can be divided into two groups: The first group contains dialogical moves of an argumentative nature, whereas a second group assesses those propositions that introduced new information and inferences into the conversation in a non-argumentative manner (see Table 1). Argumentative moves are those contributions which content and intent clearly indicate that the speaker posed a position *x*, or made a move to strengthen or weaken the epistemic status of a certain position, *x*. Non-argumentative, on the other hand, contain an addition to or expanding of the information that was provided in the preceding dialogue, *provided* that this addition cannot be labeled as argumentative in nature. It includes both instances of elaboration and of providing and requesting information (see Table 1). Acts of simple repetition or correction of the content that appeared in preceding contributions, without significantly adapting or adding new information to it (e.g., paraphrases, corrections of mistakes), are disregarded.

Table 1: Categories of different dialogical moves.

Category	*Description of category*
Claim	A proposed solution *s* (or part of it) to the ducks phenomena
Request for claim	Request for a solution, or request for an evaluation of a proposed explanation (or part of it) or to take a stance towards a solution that has been proposed.
Support	Any verbal, *reasoned* utterance that is intended to strengthen the epistemic status of an explanation x.
Agreement	Overt verbal utterances of unreasoned agreement, a simple reconfirmation of the correctness of (part of) a certain *s*, provided that it is embedded in a non-critical preceding constellation
Challenge	Any verbal, *reasoned* utterance intended to weaken the epistemic status of a solution *s*.
Opposition	Overt verbal utterances of unreasoned disagreement, simple opposition to (part of) a certain solution *s* without providing any further justifications / reasons of why they think so.
Rebuttal	Response to a "explanation(*s*)-challenge(to *s*)" chain that is intended to strengthen the epistemic status of *s* by weakening the challenge to *s*
Concession	Any overt verbal expression of agreement in a critical constellation, that is: when the content the discussant agrees to was previously opposed by him/her
Request for information	Request for further information or clarification (this excludes questions that are intended in a critical way, to questions the content of a previous statement)
Information	When pure information is provided (usually in response to a question) so as to clarify something that is not clear, or provide information about a subject unknown to the partner
Elaboration	One of the discussants builds upon the content of own or partner's previous turn in a co-constructive way, he is transacting on own or the partner's idea in the previous turn(s) or immediate preceding discussion, develops it, continues it
Repetition	The speech repeats the content of previous turns, does not include any new information or inferences compared to preceding discussion content

Macro-level assessment scheme: Interpersonal and socio-cognitive properties.

Each dyadic interaction was characterized on a number of socio-cognitive and interpersonal features:

1. *Argumentative structure of the dialogue*: Two different types of argumentation were distinguished (Asterhan & Schwarz, 2007b): (a) *Dialectical argumentation*: The dialogue contains more than one solution which Ss feel obliged to choose from, or the dialogue contains a single proposed solution that is both contested as well as defended; (b) *One-sided argumentation*: Ss only provide justifications and explanations in favor of a certain solution.

[1] This is somewhat similar to what Hogan, Nastasi & Pressley (2000) termed a 'statement unit'.

2. *Key issues of change*: Whether students discussed the key issue of *how* the ducks' feet could have changed from "feet like those of pigeons" to "webbed feet". It should be noted that giving a Darwinian-type solution is not required on this dimension; it only relates to whether they gave the issue some explicit consideration, or not.
3. *Interpersonal distribution of solutions*: Whether the dialogue moves that testified of different explanatory schemas were contributed by different interlocutors, or not (Baker, 2003). Note that a dyad might conduct a dialectical argumentative discussion without interpersonal distribution of views.
4. *Closure*: Whether the dyad agreed upon a certain solution at the end of the dialogue or not.
5. *Symmetry*: The extent to which the dyadic partners contributed evenly to the discussion, or not (Baker, 2002b). Operationally, symmetry was defined as the number of significant contributions that were proposed by the most contributive partner in the dyad, divided by the total number of such statement units in the dialogue. Significant contributions are those dialog units that contain newly asserted information, i.e., any of the contributions categorized as claims, supports, challenges, rebuttals, information and elaborations.

Results

Since the nature of the dyadic interaction and the dialogue is the mutual product of both interlocutors, the unit for statistical analyses in this design is the dyad and conceptual change should therefore also be defined on the dyadic level. In nine of the sixteen dyads at least one of the students attained conceptual change. The dialogical features of these nine dyads (hereafter referred to as the *gaining dyads*) were then compared to those of the seven remaining dyads, in which none of the dyadic partners attained conceptual change (hereafter referred to as the *non-gaining dyads*). Analyses on features of the dialogues' microstructure were conducted with Mann-Whitney tests for non-parametric independent samples and are presented in Table 2.

Table 2. Mean number (and SD) of different dialogical moves for gaining and non-gaining dyads.

Dialogical moves	*Type of dyad*		*p value*
	Gaining dyads *n*=9	*Non-gaining dyads* *n*=7	
Claim	2.00 (.87)	1.43 (1.33)	*ns*
Request claim	2.22 (1.71)	.71 (.76)	*ns*
Agreement	5.89 (3.89)	5.57 (3.78)	*ns*
Support	4.11 (3.51)	3.86 (2.85)	*ns*
Challenge	5.33 (1.33)	1.43 (2.51)	.013
Rebuttal	3.56 (1.33)	2.85 (3.86)	*ns*
Opposition	1.00 (1.12)	.57 (.98)	*ns*
Concession	1.00 (1.32)	.29 (.49)	*ns*
Elaboration	7.33 (3.84)	8.43 (5.47)	*ns*
Request information	1.11 (1.27)	.86 (1.07)	*ns*
Information	1.33 (1.87)	.29 (.49)	*ns*
Total moves of dialectical argumentation [a]	10.89 (5.84)	4.86 (3.44)	.024
Total moves of consensual construction of explanation [b]	17.33 (8.87)	17.86 (8.63)	*ns*
Total number of dialogue units	2.44 (2.96)	1.14 (1.46)	*ns*

[a] Total number of oppositions, challenges, rebuttals and concessions in a dialogue.
[b] Total number of supports, agreements and elaborations in a dialogue

The results presented in Table 2 show that the dialogues of dyads in which at least one dyadic partner attained conceptual change were characterized by a larger number of claims, requests for claims, challenges, rebuttals, oppositions and concessions. More importantly, they did not differ in the number of supports and agreements that were found in the dialogue. As for the dialogical moves in the non-argumentative category, non-gaining dyads were found to have made more elaborations, an about equal number of requests for information and less informative moves. However, the within-group variance was relatively large on most measures and only the number of challenges reached significance.

This shortcoming aside, the pattern that emerges from these finding is that gaining dyads made a larger number of argumentative moves that are of a dialectical nature (challenges, rebuttals, concessions and oppositions). Agreements and supports, on the other hand, are argumentative moves that by themselves are not of a dialectical nature (even though they may appear in a dialectical constellation alongside dialectical moves), whereas propositions of and request for claims could be interpreted as either. Elaborations have in common with

agreements and supports that they are involved in processes of consensual explanation construction. Even though an elaboration is an act of explanation *development* and a support or agreement acts of explanation *validation*, they are all of a consensual nature in relation to the explanation or claim that was proposed. Based on these perceptions, two aggregate measures were compiled, each considered to capture certain dialogical moves that are typical of two different socio-cognitive processes: (1) Total number of the dialogical moves that are typical of dialectical argumentation (consisting of challenges, oppositions, rebuttals and concessions); (2) Total number of the dialogical moves that are typical of consensual, non-dialectical construction and solidification of an explanation (consisting of supports, agreements and elaborations). Whereas the non-gaining and gaining dyads equally engaged in consensual construction, gaining dyads were found to have used a substantively larger number of dialogical moves that testify of dialectical or critical reasoning.

The gaining and non-gaining dyads were then compared on each of the macro-dimensions (see Table 3). The data in Table 3 show that the interactions of gaining dyads were more likely to be characterized by interpersonal distribution of explanatory schemas among discussants and be of a dialectical nature. However, the dialogues of gaining and non-gaining dyads did not significantly differ in whether the partners reached closure at the end the discussion and whether they discussed the critical issue of how the duck's feet could have changed.

Table 3. Macro-level dialogue properties of gaining and non-gaining dyads.

Dialogue characteristic		*Type of dyad*		χ^2 (N=16)
		Gaining dyads (n=9)	*Non-gaining dyads* (n=7)	
Interpersonal distribution of schemas	Not distributed	0	6	12.34***
	Distributed	9	1	
Key issue of change	Not discussed	0	3	4.75
	Discussed	9	4	
Closure at end of discussion	No closure	1	1	.04
	Closure	8	6	
Argumentative macrostructure	One-sided	0	5	9.35**
	Dialectical	9	2	

As for symmetry in the collaborating partners' contributions to the discussion, a Mann-Whitney test for nonparametric independent samples yielded the following: In dialogues of dyads in which at least one attained conceptual change, the highest contributing partner accounted for 54% of the total number of significant contributions on average (SD = 5%), compared to 67% for dyads who did not change their conceptual understanding (SD = 13%). In other words, significant contributions were more evenly distributed among interlocutors in dialogues of gaining dyads, than in non-gaining dyads. However, this difference failed to reach significance.

Since in spite of the task design, five dyads did not engage in *dialectical* argumentation, the possibility was tested that this may have been the result of random pairing: It is possible that a larger number of the one-sided dyads held similar pre-conceptions on evolution than the dialectical dyads did. However, an examination of the students' pretest levels of conceptual understanding revealed that the one-sided dyads were not more likely to have similar pre-conceptions (60%) than the dyads that managed to conduct a dialectical discussion (64%).

Discussion

The goal of this paper was to increase our understanding of processes of conceptual change through peer interaction. The focus was on student dialogue and the condition investigated was argumentation within a cognitive conflict-inspired task design. Dialogue and interaction features of dyads of which at least one of the students attained conceptual change were compared to those of dyads in which none of them did. The results of these quantitative dialogue analyses clearly identified processes of dialectical argumentation as a crucial factor for achieving conceptual change through peer dialogue. Consensual co-construction and elaboration of explanations, on the other hand, could by itself not predict consequent substantive changes. In addition, the different perspectives that are discussed in dialectical argumentation should preferably be represented by different dialog partners.

In many ways it is surprising that processes of consensual co-construction of explanations, by elaborating, justifying and supporting explanations, were not found to contribute to radical conceptual change. The acts of explanation and of arguing in favor of that explanation are both epistemic activities (Ohlsson, 1995) that are thought to lead students to externalize, clarify and organize their knowledge (de Vries, et al, 2002). Indeed, empirical research has provided extensive evidence that explanatory and elaboration-based activities promote both declarative learning and problem solving (e.g., van Boxtel, et al, 2000; Chi et al, 1994; Coleman, 1998; King &

Rosenshine, 1993; Okada & Simon, 1997; Webb, 1989). However, these studies did not study its role in radical conceptual change. In a sense, the findings presented in this paper confirm the expectations articulated by de Leeuw and Chi (2003) that (self-) explanation may not be sufficient to bring about *radical* conceptual change. Without the critical examination of naïve theories and consideration of different perspectives, students may merely elaborate and strengthen their initial misconceptions, even within an environment that is designed to elicit cognitive conflict. By asking students to engage in acts of explanation, elaboration and justification, they *may* become aware of flaws in their naïve theories, which in turn may trigger dialectical argumentation. However, in the majority of cases this will not occur naturally (Asterhan & Schwarz, 2007b) and is probably contingent on explicit instructions, particular task designs, individual capabilities and practice.

Subsequent qualitative analyses of the sixteen dialogues that were analyzed in this paper confirmed the necessity of engagement in reasoned argumentation on the strengths and weaknesses of one or more explanations (Asterhan, 2007). However, it also revealed that it was not a sufficient condition by itself. In particular, without episodes of consensual co-construction students did not seem to be able to make the cognitive leap. To some extent, this corroborates with findings by Chan, et al (1997) who reported that only when conflict was followed by knowledge construction did students obtain learning gains. Moreover, not just any form of engagement in dialectical argumentation was found to promote conceptual change: Students will have to juxtapose the different explanations that are proposed and engage in *co-constructive criticism*: The episodes of dialectical argumentation in most of the gaining dyads' dialogues were characterized by a pleasant and constructive atmosphere, not by interpersonal conflict or antagonism. In some of the dialogues students employed sophisticated techniques, such as spontaneous role-playing and posing "what if…" questions, in order to critically challenge different ideas without explicitly attacking the other or his/her views (Asterhan & Schwarz, in press). This presumably allowed them to critically explore different perspectives, but preserve a productive and constructive atmosphere of collaborative problem-solving and reach a better understanding therefore.

Research into conceptual change is rooted in two quite different research traditions: In developmental psychology, research aims at meticulously describing recurring and stable differences in knowledge structures of different age cohorts, whereas in instructional psychology and science education the focus is on the effects of instructional designs on students' conceptual knowledge. Neither of these research traditions, however, directly investigates conceptual change as it happens. Even though this deficit was already observed by diSessa and Sherin (1998) almost a decade ago, the field of conceptual change still lacks research that directly observes these processes. Detailed analyses of think-aloud and dialogue protocols can provide valuable insights into the process and nature of conceptual change, as the present article and deLeeuw & Chi (2004) have shown. Alternatively, one may consider the application of micro-genetic designs to the field of conceptual knowledge. Micro-genetic methods of investigation were originally developed within the field of procedural and strategy learning (e.g., Siegler, 1996). However, a recent study by Opfer & Siegler (2004) has convincingly shown its applicability and relevance for the study of concept learning. In any case, independently of the particular method that is adopted, such direct investigations into the processes of conceptual change may provide new insights into the processes of conceptual change.

References

Asterhan, C. S. C. (2007). The role of argumentation in concept learning within the socio-cognitive paradigm: The case of evolutionary theory. Unpublished doctoral dissertation. Hebrew University of Jerusalem.

Asterhan, C. S. C., & Schwarz, B. B. (in press). Peer argumentation that fosters concept learning: Maintaining the balance between critical dialogue and interpersonal harmony. To appear in: B. B. Schwarz, T. Dreyfuss, & R. Hershkowitz (Eds), *Guided construction of knowledge in the classroom*. Advanced Series in Learning and Instruction. Amsterdam: Elsevier Press.

Asterhan, C. S. C., & Schwarz, B. B. (2007a). Conceptual change in evolutionary theory: The effects of scripted argumentative monologue in peer settings. In: S. Vosniadou, D. Kayser & A. Protopapas (Eds), *Proceedings of EuroCogSci07, The European Cognitive Science Conference* (143-148). East Sussex: Lawrence Erlbaum Associates.

Asterhan, C. S. C., & Schwarz, B. B. (2007b). The effects of monological and dialogical argumentation on concept learning in evolutionary theory. *Journal of Educational Psychology, 99,* 626-639.

Baker, M. (2003). Computer-mediated interactions for the co-elaboration of scientific notions. In: J. Andriessen, M. Baker, & D. Suthers (Eds.), *Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments.* Utrecht: Kluwer Academic Publishers.

Baker, M.J. (2002a). Argumentative interactions, discursive operations and learning to model in science. In P. Brna, M. Baker, K. Stenning & A. Tiberghien (Eds.), *The Role of Communication in Learning to Model*, 303-324. Mahwah N.J.: Lawrence Erlbaum Associates.

Baker, M.J. (2002b). Forms of cooperation in dyadic problem-solving. *Revue d'Intelligence Artificielle, 16*(4-5), 587-620.

van Boxtel, C., van der Linden, J., & Kanselaar, G. (2000). Collaborative learning and the elaboration of conceptual knowledge. *Learning & Instruction, 10,* 311-330.
Chan, C., Burtis, J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition & Instruction, 15*, 1-40.
Chi, M. T. H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences, 14*, 161-199.
Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal of the Learning Sciences, 6*, 271 - 315.
Chi, M. T. H., DeLeeuw, N., Chiu, M., & Lavancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science, 18*, 439-477.
Coleman, E. B. (1998). Using explanatory knowledge during problem solving in science. *Journal of the Learning Sciences, 7* (3&4), 387-427.
DiSessa, A. A. & Sherin, B. L. (). What changes in conceptual change? International *Journal of Science Education, 20*, 1155-1191.
Doyle, J. A., & Sinatra, G. M. (1998). Reconceptualizing change in cognitive construction of knowledge. *Educational Psychologist, 33*(2/3), 109-128.
Gentner, D., Brem, S., Ferguson, R. W., Markman, A. B., Levidow, B. B., Wolff, P. and Forbus, K. D. (1997). Analogical reasoning and conceptual change: a case study of Johannes Kepler. *Journal of the Learning Sciences, 6*, 3-40.
Keil, F. C. (2006). Explanation and understanding. *Annual Review of Psychology, 57*, 227-254.
King, A. & Rosenshine, B. (1993). Effects of guided cooperative questioning on children's knowledge construction. *Journal of Experimental Education, 61*(2), 127-148.
deLeeuw, N. & Chi, M.T.H. (2003). Self-explanation: Enriching a situation model or repairing a domain model? In: G. Sinatra & P. Pintrich. *Intentional conceptual change*. Hillsdale, NY: Erlbaum (p. 55-78).
Limon, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Learning & Instruction, 11,* 357-380.
Ohlsson, S. (1996). Learning to do and learning to understand: A lesson and a challenge for cognitive modeling. In: P. Reimann & H. Spada (Eds), *Learning in humans and machines: Towards an interdisciplinary learning science* (37-62). Oxford: Elsevier Science Ltd.
Ohlsson, S. (2002). Generating and understanding qualitative explanations. In: J. Otero, J.A. Leon, & A.C. Graesser (Eds), *The psychology of science text comprehension* (91-128). Mahwah, NJ, US: Lawrence Erlbaum.
Ohlsson, S. & Bee, N. V. (1992). *The effect of expository text on students' explanations of biological evolution.* OERI Report. Learning Research and Development Center, University of Pittsburgh.
Okada, T. & Simon, H.A. (1997). Collaborative discovery in a scientific domain. *Cognitive Science, 21,* 109-146.
Opfer, J. E. & Siegler, R. S. (2004). Revisiting preschoolers' living things concept: A microgenetic analysis of conceptual change in basic biology. Cognitive Psychology, 49, 301-332.
Piaget, J. (1985). *The equilibiration of cognitive structures*. Chicago: University of Chicago Press.
Rogoff, B. (1998). Cognition as a collaborative process. In: W. Damon (Series Ed) and D. Kuhn (Vol Ed), *Handbook of child psychology, vol. 4, 5th Ed* (679-744). NewYork: Wiley.
Schwarz, B. B., & Linchevski, L. (2007). The role of task design and of argumentation in cognitive development during peer interaction. The case of proportional reasoning. *To appear in Learning and Instruction*.
Schwarz, B. B., Neuman, Y., & Biezuner, S. (2000). Two wrongs may make a right...if they argue together! *Cognition & Instruction, 18*, 461-494.
Siegler, R.S. (1996). *Emerging Minds: The process of change in children's thinking.* Oxford: Oxford University Press.
Vosniadou, S. & Brewer, W. F. (1994). Mental models of the day / night cycle. *Cognitive Science, 18,* 123-183.
de Vries, E., Lund, K., & Baker, M. (2002). Computer-mediated epistemic dialogue: Explanation and argumentation as vehicles for understanding scientific notions. *Journal of the Learning Sciences, 11*, 63-103.
Walton, D. (2006). Fundamentals of critical argumentation: Critical reasoning and argumentation. New York, NY: Cambridge University Press.
Webb, N.M. (1989). Peer interaction and learning in small groups. *International Journal of Educational Research, 13*, 21-39.

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