Emergent learning in successive activities

Learning in interaction in a laboratory context*

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The present study focuses on the observation of learning processes as they emerge in the context of conversations among two students in three successive tasks designed to foster conceptual change in proportional reasoning. The three tasks were set according to a pre-test treatment post-test paradigm. In the pre-test and the post-test tasks, the two students solved individually several items in the presence of an experimenter. In the treatment task, the two students worked as a dyad to solve similar items; they used a balance to check their conclusions and subsequently continued solving the items when the weighing did not match their expectations. We adopt a micro-genetic approach and develop new analytical tools to observe what happened in the conversation (both socially and cognitively). Throughout the three successive tasks, we observed the interplay between tools, peers, experimenter, and task demands and how they are managed through the rules of conversation. We identified four processes that involved the *emergence* of new high-order strategies from coordinated actions distributed among peers, the *guidance* of the experimenter in coordinating actions, and ways the participation in solving a previous task was actualized in a successive one.

Keywords: learning in interaction, interlocutory analysis, conceptual development, emergent learning, collaborative learning, proportional reasoning

1. Introduction

In the present study, we aim at observing learning processes as they emerge in the context of successive conversations. Although many studies have already been conducted on learning in conversation (e.g., see the series of studies in *Apprendre dans l'interaction* by Gilly, Roux, and Trognon 1999), only few studies focused on *conceptual learning* in dyadic interaction (e.g., Roschelle 1992) or in successive

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group activities (e.g., Carraher and Schliemann 2002). The important methodological and theoretical contributions proposed by Engeström (2004) to describe (expansive) learning in successive activities at workplace or in professional development are not easily adaptable to activities centered at the development of individuals, like in the present study. This study is novel since it is about processes involved in *conceptual change* — hence in more radical modifications than in conceptual learning — in *successive* dyadic conversations. It follows a prior study, in which inferential statistics were used to show conceptual change in individuals across a sequence of structured tasks designed to promote proportional reasoning. We describe the prior study in the next section, as it helped choosing a 'good dyad' for our study. The present study is a modification of the first one, so that the description of the prior study shortens its description.

2. A prior study on conceptual change in proportional reasoning through dyadic interaction

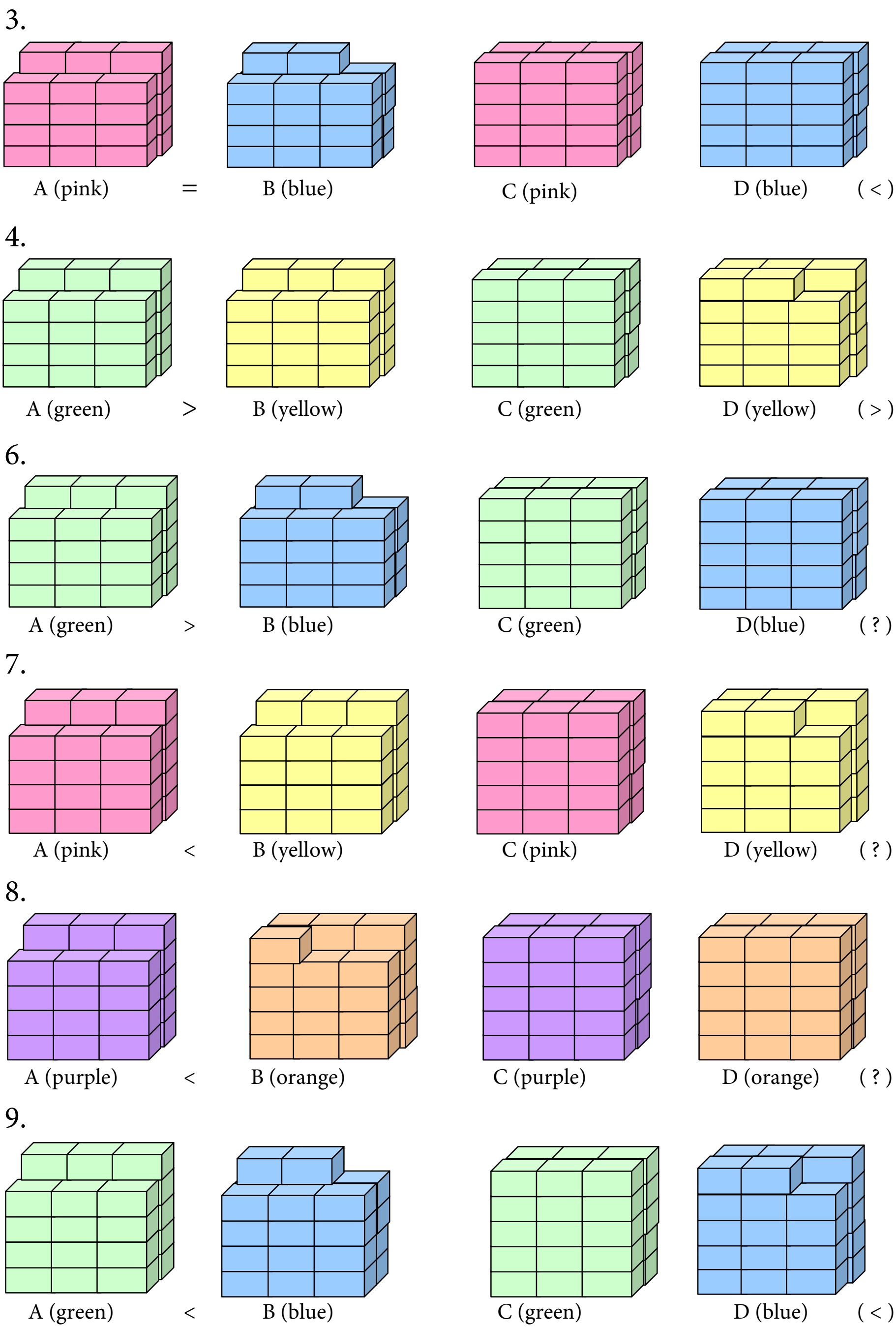
Schwarz and Linchevski (2007) recently tested effects of dyadic interaction on proportional reasoning in an experiment including a pre-test, a treatment, and a post-test. The experiment is based on a modified version of the 'Blocks task' (Harel, Behr, Post, and Lesh 1992) that showed that the Blocks task provides a clearer window than other tasks to observe children's reasoning about proportionality: the balance scale task (Inhelder and Piaget 1958; Siegler 1976), the rate and mixture task (Noelting 1992), and the fullness task (Siegler and Vago 1978) involve more extraneous physical principles that interfere on reasoning about proportional constraints. Moreover, the Blocks task is cognitively more demanding than the other tasks; thus it allows the emergence of a broader range of performances that fit into

The child receives written insructions. The experimenter puts the blocks of the first item on the table and reads the instructions with the child:

> ***"You are asked to answer a task with 9 parts. In each part, I will show you two pairs of blocks, the pair (A, B) and the pair (C, D). Bricks with the same color have the same weight. In each part, I'll tell you whether A is heavier than B, lighter than B, or weighs the same as B. You should decide whether C is heavier, lighter or weighs as D. You may say that it is impossible to decide"***

The directives are the same for the pre-test and the post-test. For the phase of interaction, the dyads solve the task together. They use a balance to check their first conclusions. If the weighing conflicts with their conclusions, they are invited to continue their discussion. We show here only the items discussed in the paper:

Figure 1. The Modified Blocks Task



Correct answers are inscribed between parentheses a comprehensive research-view on proportion, and enables comparison with performances in other tasks (see Harel et al. 1992).

In the individual (modified) version of the Blocks task, the student is shown two pairs of blocks (A, B) and (C, D) (see Figure 1). All blocks are built of bricks with identical sizes. The bricks in A and C (resp. in B and D) have the same color. All bricks with the same color weigh the same. The task is administered in nine configurations in which blocks A and C have 27 and 30 bricks respectively (see Figure 1). The number of bricks in B and D (labeled in this article as n(B) and n(D)) vary. Students are informed about the relative weight of A and B. The three alternatives are A heavier than B (noted as $w(A) > w(B)$ or simply $A > B$), $A = B$ and $A < B$. Students are then asked to decide about the relative weights of C and D.

In its collective version, at a first stage, dyads are presented two sets of blocks. They are invited to discuss the relative weight of C and D and to try to reach a consensus. During the discussion, the experimenter is supposed to ask for clarifications about actions and utterances whenever she does not understand what children meant, and to flag the purpose of the task — to accommodate divergent views, when she deems it necessary. At the time peers reach a conclusion, the experimenter brings a balance and two other sets of blocks with exactly the same configuration (see Figure 2). She then asks students to weigh the three pairs of blocks. If the answer to the item is one of the relation <, >, or =, then the weighing shows three times the same relation. If the answer is indeterminate, then the three weighings successively show the relations <, >, and then = in order to convey the idea that it is impossible to know. When the weighing contradicts the conclusions

Figure 2. The weighing of the blocks

reached, the experimenter asks students to discuss and explain "what happened". Again she intervenes when necessary to elicit reaching consensus and to clarify unclear utterances.

Schwarz and Linchevski hypothesized that when interacting while solving the blocks task, students of different levels will use different strategies, and hence will often be lead to disagree, that the balance will often confront dyads with answers different from theirs and that this should lead them to engage in argumentative activity. They then expected the level of proportional reasoning to change since argumentation has been shown positively related to construction of knowledge (e.g., Kuhn, Shaw, and Felton 1997; Schwarz, Neuman and Biezuner 2000; Schwarz, Neuman, Gil, and Ilya 2003). The experiment was organized in three phases: 60 ten graders, low achievers (in mathematics) were first asked to solve individually the nine first items of the Blocks task. 32 of the students were then invited to collaboratively solve Items 5, 7, and 9 from the blocks task in 16 dyads. Three weeks after the interaction, all 60 students participated in the post-test interview in which they solved only items 3, 4 and 8 from the Blocks task (items in the interaction and in the post-test were different to avoid retrieving without understanding but similar enough to measure learning gains). The measurement of the level of proportional reasoning was mainly based on the identification of strategies of resolution. The strategies appeared in the explanations students gave when asked to justify their decisions. Four kinds of explanations evidencing four different strategies were identified in the pre-test:

S0, Wild Guess: The child totally ignores blocks A and B. The explanations are tautological or vague. An example is "D is heavier, it's just what I think".

S1, Visual explanations: Judgment is based on visual features of blocks C and D or on the counting of the number of bricks in C and D without relating to blocks A and B.

S2, Additive explanations: Here, to base his or her judgment, the child relates to blocks A and B to consider the difference between the number of bricks. He or she can consider difference between A and B vs. difference between C and D or difference between A and C vs. difference between B and D.

S3, Proto-proportional explanations: Here also, the child bases his or her judgment on relating C and D to A and B. However this time, the weight of bricks relatively to whole blocks is considered. If for example, A and B have the same number of bricks, and A is lighter than B, the child infers that each brick in A is lighter than in B, and uses this information to decide on the relative weight of C and D. Such explanations attest the beginning of proportional reasoning. However, such explanations do not attest a full proportional reasoning, as the child also needs to consider discrepancies between blocks relatively to the relative size of the blocks. Students in the pre-test did not express this kind of explanation. However, we gave the Blocks task to some high school students with high-level ability in mathematics and identified fully proportional explanations:

S4, Fully proportional explanations: One of the explanations was expressed while solving Item 9 by a high-ability student that did not participate in the experiment (see Figure 1 to follow the explanation): "26 bricks of B weigh more than 27 bricks of A; In D there are 29 bricks and in C 30. I know that 26/27 is less than 29/30 so, for sure D will be heavier". Although S4 explanations were not identified during the pre-test, we envisioned that the experiment could afford their expression.

It is important to note that, as the level of explanation increases, the number of components to be taken into account increases: S0 explanations do not clearly refer to the size of C and D, and totally ignore A and B. S1 explanations actually compare C with D, but disregard A and B. S2 explanations take all four blocks into account, but only in terms of additive differences. S3 explanations point to recognition of proportions between A and B, but still consider differences when comparing C and D. S4 explanations take all four blocks into consideration in terms of two different proportional relations. This feature will be central to understand why social interaction (with a peer or the experimenter) is crucial for higher strategies to emerge.

Schwarz and Linchevski (2007) showed that the different strategies often lead to different results and thus to disagreement, triggering argumentation. The level of proportional reasoning in the experimental group was found significantly higher in the post-test than in the pre-test. The fact that many of the students used additive strategies in the pre-test and used multiplicative strategies in the interaction and in the post-test can be referred to as *conceptual change* (see Harel et al. 1992, who explain the general character of the Blocks task with regard to other tasks on proportions). Schwarz and Linchevski observed that (a) strategies are often not used systematically, (b) the same instability occurs in the post-test although it is less accentuated, (c) no student used a S4 strategy, (d) for some students, the use of S3 strategies is systematic in the post-test and follows the elaboration of S3 strategies in the interaction; for others, S3 strategies whose use is initiated in the interaction are not systematically used in the post-test or vanish in the post-test. These fluctuations did not tell us about the processes that accompanied conceptual change, and raised questions such as: Is 'what is learned' a compliance (lip service to social demands) or rather an autonomous co-elaboration of higher-level proportional strategies and its re-contextualization in further activities? A third issue, related to the second one, concerns design: is the design so preponderant as to afford desirable answers?

Developmental psychologists may suggest answers to these issues. For example the *overlapping waves theory* (Siegler 2004) suggests that, in the evolution of their strategies, children typically use a variety of strategies which coexist over prolonged periods; they adjust their choices of strategies to problem characteristics; learning occurs through processes such as the acquisition of new strategies, increasing reliance on most effective strategies, or superior choices among strategies. However, the kinds of answers we seek are different: our specific aim in the present study is to *understand* how two adolescents learn to reason proportionally across a structured sequence of tasks. We will undertake a step by step observation of the three phases of the experiment in order to trace how individual and collective knowledge are transformed. We will observe how agents, tools, and the design of task itself support the evolution of the individual/collective thinking. In particular, although the experimenter is supposed to intervene in two cases only (to ask for clarifications concerning unclear utterances and to refocus students on task), as it is often the case in any professional activity, it might be that there is a difference between the "assigned role" and the "acted role".

3. Description of the present study

The use of strategies in Schwarz and Linchevski's study was minimal in the sense that it depended on whether the use of a lower strategy was sufficient to solve the task. For example, additive explanations in Items 2 and 4 sufficed to produce a correct answer. In Items 5, 6, and 7, the same subjects used S3 strategies, as considering the relative weight of bricks seems to them self-evident. S4 strategies were unnecessary. In the present study, we invited a new dyad from the same population (two ten graders low-level male students in the same school, named Itay and Shay) to participate in the experiment. The experimental plan was identical except for a new item (Item 10, see Figure 3) added to the dyadic interaction phase to *afford* S4 strategies. Indeed, S3 explanations in item 10 inexorably lead to a wrong answer: S3 students would infer from the fact that A and B weigh the same that each brick in A weighs more than in B and that it is then impossible to decide

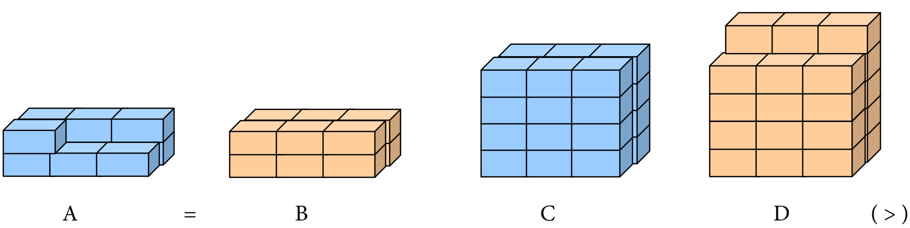


Figure 3. Item 10 affords the adoption of full proportional strategies

which of the blocks C or D weighs more. S2 students would typically notice that A and B weigh the same while there is a deficit of two bricks in A. Since in C there is a deficit of three bricks, adopting a S2 strategy would lead to the conclusion that D weighs more than C. The feedback of the weighing contradicts these answers and shows that C weighs more than D. The students were invited to solve Item 10 in addition to Items 5, 7, and 9 in the dyadic phase. The experimenter's role was to present the blocks, to read the instructions, and to intervene only for asking for clarifications and refocusing on task. We first present a general picture of Itay and Shay's performance.

3.1 General picture of Shay and Itay's performances

In the pretest, Itay generally uses S2 explanations to decide which of the blocks is heavier. He fails to solve five out of the nine items. As for Shay, he fails to solve four items in the pre-test. He alternatively uses S2 and S3 strategies. In the phase of interaction, Shay and Itay succeed to solve all tasks. They gradually abandon S2 strategies for the sake of S3 strategies for Items 5, 7 and 9. When solving Item 10, Shay and Itay co-articulate S4 explanations. In the post-test, Shay and Itay generally adopt S3 explanations. Shay and Itay succeed in all tasks except for item 4 that Itay fails to solve (although his explanations remain proto-proportional). In item 8, Itay shows the same strategy to solve it successfully. Shay's post-test strategies are steadily proto-proportional. In item 8, his explanations even go beyond S3 strategies:

> Shay: It's impossible to know because in B there are more boxes than in A and it weighs more and in C and D where it's the same, so I don't have data with which I can decide between these two boxes in C and D. If there had been one box more in D, I could have said that D weighs more than C, but since they are the same, I can't know.

This general picture fits the results of the prior experiment: The interaction phase in which *new* strategies develop; the post-test in which Shay seems to use the new learned strategy and in which Itay successfully uses some strategies but is quite inconsistent. Time has come now to understand how Shay and Itay learn to reason proportionally across the three stages of the experiment, and by such to address the questions the first study raised: the description of the processes of the transformation of individual/collective knowledge, the issue of autonomy in the co-elaboration of new strategies and the role of design. In a study on the same corpus, Trognon et al. (2006) identified intersubjective processes that modified cognitions. This analysis, based on *Interlocutory Logic* (Trognon 1999), focused on a limited part of the interaction phase. The method yielded a formal proof of deductions and inferences made by the subjects in the conversation. However, *Interlocutory Logic* is not yet adaptable for analyzing large corpuses of data. We then simplified the method (described below) to provide support for interpretations instead of proofs. To describe transformation of knowledge, we naturally focused on the development of a *new strategy*. Item 7, which both students failed to solve in the pre-test and solved in the interaction phase while using S3 strategies seems a good choice.

4. The emergence of a new strategy in peer interaction

Let us first turn to a detailed consideration of items 6, and 7 (see Figure 1) of the pre-test compared to item 7 of the interaction (items 6 and 7 are similar).

4.1 Itay in the pre-test

Table 1 shows Itay's protocols for item 6, the interlocutory force of all utterances in the protocol, and their propositional contents. The method of analysis is inspired by Trognon's (1999) *Interlocutory Logic*. Two columns are dedicated to illocutionary forces. The first column, the type, is inspired by Vanderveken's General Semantics (1988). It indicates the different interlocutory goals (Assertive (A), Directive (Di), Expressive (E), Committing (Com), Declarative (Dec), Permissive (Perm), Questioning (Q)) defined in the force of the speech acts expressed by the interlocutors.[1] They are put in relation with their intersubjective interpretation in the context of the activity, as shown in the second column. In this column, the categories are: *explanation, *clarification, *elaboration, objection, *agreement, concession, refutation, reference to a previous task, *suspension and *conclusion/response. The asterisk means a possible request: an interlocutor may request clarification, elaboration, agreement, suspension or conclusion. All categories up to concession are common in conversations (see, for example, Resnick et al. 1993). Other categories characterize conversations in school in the course of successive problem solving activities, especially conclusion/response. Since the statements of the students are often elliptic, our formal descriptions have the status of plausible hypotheses to be tested further on, as the conversation develops. We show later on how these hypotheses are validated or refuted according to what happens in the following turns of the interaction. The formal description of propositional contents may seem complicated for readers without mathematical background but this is not the case: for example, the content $\{n(B) = n(A) - 1\} \Rightarrow \{w(A) > w(B)\}$ discussed in the next paragraph, should be read "[if] the number of bricks in B is equal to the number of bricks in A minus 1, then A weighs more than B". Adopting these conventions eases the understanding of the fine-grained analysis of the protocols. However,

Table 1. Itay's pre-test

Table 1a. Item 6

Sequential	Illocutionary force		Propositional content
	Type	In context	
1Itay1: A weighs more than B?	?Q	Clarification	$\{w(A) > w(B)\}$
1Itay2: C is heavier than D	A	Conclusion/ response	$\supset\{w(C) > w(D)\}$
1Itay3: No…One moment	Pause		
1Itay4: A is heavier because there are more box	A	Elaboration	$\{n(A) > n(B)\} \supset \{w(A) > w(B)\}$
1Itay5: Then I think that both are the same	A	Conclusion /response	$\{w(C) = w(D)\}$
1Itay6: This (A) is heavier than B	A	Explanation	$\{w(A) > w(B)\}$
1Itay7: Because here (B) a box is missing in comparison with A	A	Explanation	$\{n(B) = n(A) - 1\} \supset \{w(A) > w(B)\}$
1Itay8: And here they have the same dimensions	A	Explanation	$(\{n(C) = n(D)\}$
1Itay9: Then I think that their volume will be the same	A	Conclusion/ response	$\supset \{w(C) = w(D)\})$

readers preferring to skip the details of these formalizations should not lose track of the arguments we develop below because we will try to convey in full text the results of this detailed analysis. We proceed now to a fine-grained step-by-step description of the pre-test of Itay. Further on, we will describe Shay's pre-test and compare the two protocols to fine grained descriptions of the interaction phase.

An interesting characteristic of the protocol is that Itay elaborates his reasoning process as an uninterrupted argument (from 1Itay1 to 1Itay7 in Table 1 — the "1" before Itay represents the turn — here there is one turn only). All the interlocutory categories in context (clarification, conclusion/response, elaboration, explanation) suggest that Itay is deeply engaged in solving the task. In 1i4 (for 1Itay4), 1i7 and 1i8, it appears that Itay grounds his decisions on the number of bricks in A and in B ($\{n(A) > n(B)\} \Rightarrow \{w(A) > w(B)\}$ in 1i4, $\{n(B) = n(A) - 1\} \Rightarrow \{w(A) > w(B)\}$ in 1i7): Itay infers that A is heavier than B because the number of bricks in A is bigger than in B (1i4). It leads him then to the conclusion that since the number of bricks in C and in D is the same, C and D will weigh the same.

The protocol for item 7 is not shown. Itay elaborates an argument without help. He cannot rely on an explanation based on the number of bricks as in item 6, because the number of bricks in A and B is identical but A weighs more than B. The illocutionary force of his conclusion is the expression of a doubt, the doubt concerning either the correctness of his answer, or the legitimacy of the answer ("it is impossible to decide"), or both of them.

4.2 Shay in the pre-test

Shay's reasoning generally appears in the form of arguments elaborated in one turn without help, except for item 6. In item 6, Shay elaborates a reasoning process that can be possibly identified as proto-proportional: *We know that A is heavier than B but in A there are more boxes, we may think of a situation where blues are heavier than yellows and we don't know how much heavier they are*. Shay shows here that he tries to infer the weight of the bricks of which A and B are constituted from the weight of A and B. It is interesting to notice that it is after the intervention of the experimenter that Shay goes deeper in his reasoning, towards the elaboration of a proto-proportional strategy: Indeed the experimenter led Shay to imagine a situation where the bricks in B are heavier than in A, hence leads him to focus his attention on the weight of "units" (bricks). Shay expresses very fluently why it is possible that w(C) = w(D), and why it may not be the case: he does this by figuring out a situation in which it would not be the case. In item 7, Shay reaches the wrong answer that C and D weigh the same. He declares, "the lack of one box in D creates a balance between C and D". In fact, he uses the relation w(a) < w(b) to infer that since there is one brick more in C than in D, this additional brick compensates for the weight of bricks in D which is bigger than in C.

For all items, Shay uses the same kinds of considerations concerning w(a) and w(b) that express the deployment of a proto-proportional strategy. In items 6 and 8, this leads to the right answer (that it is impossible to decide). In item 9, Shay regresses as instead of inferring from w(a) < w(b) that it is impossible to decide on the relative weights of C and D (a wrong but proportional answer), he uses again an additive strategy to conclude that C and D weigh the same. It appears then that in all the items, Shay is able to infer from the configuration of A and B the relation between the weights of w(a) and w(b), but is not able to manipulate this relation to compare between the weights of C and D. In other words, when Shay comes to decide about the respective weights of C and D, he takes into consideration the nature of the relation between w(a) and w(b) (<, >, or =), but uses an additive strategy to decide on the relative weight of C and D.

4.3 The interaction phase

Let us now turn to the interaction phase on item 7. As noted above, Shay and Itay who are additive in the pre-test, take all four blocks into account in their explanations, but only in terms of additive differences. Table 2 shows the protocol, the interlocutory force of all utterances and their contents. As it appears in the table, many utterances are elliptic and their contents are italicized. This is due to the fact that in peer interaction, students do not feel obligated to be as explicit as in the pre and post-test. In accordance with Trognon's method of *Interlocutory Logic*, we systematically generated hypotheses about the utterances at each step of the protocol in order to check these hypotheses later on in the course of the unfolding of the conversation. Of course two possibilities could occur. The first possibility was that only one reasonable hypothesis could be generated. The second possibility was that multiple hypotheses could be generated. For example, there are three possible interpretations to "Here it's the same" in 3i2 (noted in the Table 3Itay2). The first interpretation is that {w(D) > w(C)} (i.e., D weighs more than C, and this is the same as B that weighs more than A). The second interpretation is that {w(D) = w(C)} (i.e., D and C weigh the same). A third one could be that Itay is considering that the colors are the same in A and C on one hand, and in B and D on the other. In turn 3i2, there is no way to decide which of the three interpretations is the right one. But a close look at the next turns in the conversation shows that only the second interpretation is consistent with the rest of the protocol: for example, in 6s2 (noted 6Shay2 in the table), Shay clearly expresses his conclusion "C and D weigh the same". The other interpretations can then be abandoned at least temporarily as the assumption "C and D weigh the same" is jointly agreed upon the interlocutors. We did not insert in Table 2 all possible interpretations to ease the reader's job but kept only those confirmed by the next steps.

The episode begins with Itay's request for clarification which is satisfied by the experimenter (Turns 1 to 3) in which the starting data w(B) > w(A) is confirmed. In 3i2, Itay infers w(D) = w(C) by himself. The "Yeah" does not proceed from the

Table 2b. Item 7

Sequential	Illocutionary force		Propositional content
	Type	In context	
1Itay1: A weighs less than B	A	Clarification	{w(A) < w(B)}
1Itay2: OK! Let's check	Com		
1Itay3: I think that D weighs more	A	Conclusion/ Response	{w(D) > w(C)}
1Itay4: I'm not sure because before we saw that this is equal between them, their weight, when B is higher	E(D)	Reference to a previous task	*Content unclear*
1Itay5: Now when a box is missing, then the weight of D will remain bigger	A	Conclusion/ Response	{n(C) = n(D) –1} ⊃ {w(D) > w(C)}
1Itay6: Or they'll be equal	A	Conclusion / Response	∨ {w(D) = w(C)}
1Itay7: I don't know how to decide. I'm not sure	E(D)	Conclusion /Response	*{w(D) > w(C)} ∨ {w(D) = w(C)}*

previous turn. It expresses an emotional relation with the expression of his reasoning. At Turn 4, the inference {then, w(D) = w(C)} is articulated, although the bulk of the inference chain is left implicit (thus italicized), as shown in the formalization of 4s3c:

> If {w(B) > w(A)} and *{n(A) = n(B}) ⇒ {w(b) > w(a)} ⇒ {w(d) > w(c})*
> *⇒ w(C) < w(D + [X]) ⇒* w(C) = w(D).
> {If B weighs more than A} and *{if the number of bricks in A is the same as in B, then each brick in B weighs more than each brick in A}, then {if each brick in D weighs more than each brick in C, so that C weighs less than D 'filled with something'},* weighs the same as D}.

The certainty of this hypothesized inference is confirmed by the previous and subsequent turns: First, Shay already expresses n(A) = n(B) as a part of his reasoning in 4s3a. Also, D + [X] which represents the block D "filled" to include the same number of bricks as C,[2] is an object of reasoning, as expressed in 4s3b. The rest of the chain [*w(C) < w(D + [X]) ⇒ w(C) = w(D)*] expresses that when the relation "heavier" is weakened (by taking off some weight from the heavier pan), the subject replaces it by "equal". Such a hypothesis of interpretation is fully compatible with the subsequent objection and refutation in Turn 5: Itay objects, "Who told you that it weighs [more] by exactly one box" (5i2), a question whose content is:

> *w(D + [X]) = w(C)* + w(d)

And then refuted by "It can weigh by much more" and a new conclusion is drawn in 5i4, "It's impossible to know", whose content can be formalized as the following new inference:

> w(D + [X]) = w(C) + wd. or w(D + [X]) > w(C) + w(d)

Shay challenges Itay's inference at Turn 6. At Turn 7, Itay proposes first to return to the initial data and to clarify it (7i2), then to express some reservation concerning his own conclusion (7i3). Itay then concedes that his conclusion does not prevent him from considering Shay's different conclusion as not being completely at odds with his conclusion (7i4a). The continuation of 7i4 is a way to explain (or perhaps to exonerate) his refutation. When Itay claims in 7i4d, *so they must be more or less equal*, he concedes that Shay may be right but he also leaves the door open to his past objection. In this utterance he deploys an argumentative stratagem: Itay accounts for the two seemingly contradictory viewpoints, consequently saving Shay's face; he also gives Shay the opportunity to identify himself in what he (Itay) claims. But Itay is not really able to allow these two seemingly contradictory viewpoints to 'cohabitate': in 7i4d, *he cannot overcome the contradiction he feels from a higher-level cognitive perspective integrating the two viewpoints,* *which means developing a reasoning process of a proportional type*. Thus, in order to dodge this impasse while keeping his conciliating objective to preserve the two viewpoints, Itay enunciates the magnificent expression: "so they must be *more or less* equal"! At Turn 8, the experimenter asks for clarification about this ambiguous expression. This request serves Itay at Turn 9 to express his reservation about his conclusion. When the experimenter asks Itay about this reservation at Turn 10, it is Shay who identifies himself as Itay's *teammate* by saying, "*We* don't have data on how much each box weighs", which echoes 5i3 and 7i3. Shay seems to take a step back relatively to his previous argument and to give in turn a hand to Itay while decentring in order to defend the common conclusion agreed now by the pair (we don't know whether Shay has really appropriated the force and the content of the final conclusion by Itay in 7i4d but it is easy to infer Shay's answer "we don't have data on…" from Itay's conclusion "they weigh more or less the same". After the experimenter's clarifications that three types of answers are admissible ("one weighs more", "the weights are the same", "it is impossible to know"), Shay opts for the later one immediately.

In summary, the disagreement expressed as Itay's objection/request (5i3) to Shay is resolved through a series of exchanges leading to the appropriation and the transformation by Shay (in 11s) of the argument in Itay's objection. This transformation *explicitly* shifts the focus from blocks to bricks. This means that, for the first time, Itay and Shay refer to units, a fact that indicates a progression of the dyad regarding the correct solution, as it demands an equal (proportional) reduction of quantities to units. It illustrates the process of co-construction of an argument stemming from illocutionary forces and propositional content of previous actions and from efforts of respect of the other's point of view and hence of decentration on the part of the interlocutors. After having made an objection, Itay seems to open the way for Shay to appropriate his doubt through a concession. At the end of the interaction, the experimenter (12e) requires from Itay to express his doubt explicitly. At that moment (perhaps because of Itay's earlier concession to Shay's argument) Shay *appropriates the doubt as his*, and explains to the adult why Itay's doubt is justified. The experimenter provides then a runaway to the conversation by reminding them that there are three possible answers. Shay then concludes with "it's impossible to know".

4.4 Conclusion: emergence of a strategy through coordination of distributed arguments

We already saw that neither Itay nor Shay could solve item 7 in the pre-test; this fact led us to identify the emergence of a new co-construct in the solution of item 7 in the interaction phase. A comparison between the pre-test and the interaction phase leads to an additional insight. The objection "Who told you that it weighs by exactly one box" (5i2), refuted by "It can weigh by much more" is preceded by Shay's explanation why C and D have the same weight (in 4s3b) of a claim enunciated by Itay at Turn 3. But Itay expressed this very claim in the pre-test in 1i7 as a doubt (see Table 1). This is perhaps why Itay, who thinks exactly the same as Shay, can coordinate Shay's explanation with his doubt as an opposition, and Shay, after Itay retracts from this opposition, can capitalize on its content to articulate a proportional argument. *The new strategy emerges then as a coordination of distributed arguments*.

Let us now turn to the further emergence of full-fledged proportional strategies we expected to occur with item 10. As aforementioned, these strategies involve taking all four blocks into account to compare two proportional relations. Our aim in the next section is (a) to show how this new emergence stemmed from the emergence we just observed for Item 7, and (b) to identify whether and how Itay and Shay refer to this new emergence in their post-test.

5. Further emergence of a new strategy and its later ventures

When Itay and Shay solved item 7 the weighing confirmed their agreed conclusion. We designed item 10 to give to weighing another role, the role of contradicting previous hypotheses. Although design can only encourage answers/explanations, Itay and Shay behaved very much as expected: Up to the weighing, the strategy adopted by Itay and Shay is additive. For example, Itay confirms Shay's conclusion that D weighs more than C, and explains that *because there is one brick more, here two bricks are missing and they are equal, and here that are three bricks more. So one brick more, it gives two and so, it will weigh more*. This explanation and others are replete with the additive terms "more" and "missing". We will see that the weighing challenges Itay and Shay's arguments and leads them to their revision. We present first some explanations as milestones of progression in reasoning processes. A first example of explanation occurs just after weighing. Itay declares:

> Here there are two bricks and they are equal. I think that there should have been 5 bricks to become equal.

Later on, Itay declares (second example of explanation):

> I think that each little brick like that weighs more than any little brick. Any box in C weighs more than any box in…because I don't know that here two boxes are missing. Thus, this means that each box weighs more…

Such kinds of S3 explanations look like the explanations produced while solving item 7. Itay did not use them until he co-solved Item 7, and capitalizes on them here to face the results of the weighing. However, S3 strategies could not explain why C weighs more than D. So, Shay began developing another explanation that takes into consideration the numerical relation between the number of bricks in A and in B:

> I look at the numbers. Well, the relation here is 10 for 12. There are 10 blue boxes for 12 orange ones, and then it becomes equal. Here there are 10 for 12. Here there are 24 boxes.

In this example, Shay attempts to *link between relations*, and this is a very demanding task. He compares the relation between the number of bricks in A and B and the number of bricks in C and D. In a series of interactions not shown here, Itay suggests modifying the relation of 'number of bricks' between the two pairs of blocks by adding two bricks to D: *We should leave two more on the top, I guess*. Shay reacts to propose one brick (and not 2) to add to D so that the relation between C and D will be equivalent to the relation between A and B: "We should have had one more box so that D would be equal to C". In other words, Shay and Itay use a hypothetical mode (like on the first explanation) to figure out when C and D would have weigh the same.

But the design of item 10 'forces' them to leave qualitative considerations, and to keep on considering numerical relations:

> 37s Yeah, for 10 blue bricks, there are here 12 orange
> 38i I got it. For each 12 orange [bricks]
> 39s For each 10 blue, there are here 12 orange. So, we need to add 2 more. Here there are 24 and here 27. We must add one brick more in order to get the equilibrium, the relation must be…
> 40e You said 10 blues and 12 oranges. And here how many blues are they?
> 41s 24
> 42e 24 blues and
> 43s 27. And for 10 blues, we must add
> 44i 12
> 45s 12 oranges
> 46i So we need to add one more box to become equal
> 47s If you reach here 20, you need 4 more, as if there were two tenths here
> 48e And how much is there here?
> 49s 24
> 50e 24. So how many orange [boxes] are needed for 24?
> 51s 28
> 55s Here these are two tenths?
> 56e There are two tenths or more than two tenths?

57s Here there are two tenths but if you take off…If you take off these 4, and you take off these 3, OK, this will be exactly…
58i Equal. You got it? Because this goes with this
59s This gives 20 for 24, it's a relation of 20 for 12
60i This is more or less, although there are more boxes

Shay and Itay first compare couples of numbers (37s–39s), sharpen this relation later on, and finally demonstrate full-fledged proportional reasoning (47s, 51s, 55s–60i). In more details, in 37s, Shay initiates his reasoning by considering the relation of the number of bricks between A and B (10 et 12). He links this relation in 39s with the relation of the number of bricks between C and D (24 and 27) by proposing the addition of a brick to D. The corresponding propositional content is:

Yeah, for 10 blue bricks, there are here 12 orange	$w(10a) = w(12b) \Rightarrow \mathit{w(12a) = w(14b)}$
Here there are 24 and here 27.	$n(C) = 24, n(D) = 27$
	$\mathit{w(C) = w(24c) \wedge w(D) = w(27b)} \Rightarrow$
	$\mathit{w(24a) = w(28b)}$
We must add one brick more	$\Rightarrow (D' = D+\{d\} \Rightarrow \{w(C) = w(D')\})$
in order to get the equilibrium,	
the relation must be…	$\Rightarrow \mathit{w(C) > w(D)}$

According to our hypothesis (italicized), Shay (mistakenly) infers that if $10 \times w(a) = 12 \times w(b)$, then this equality holds when *adding the same quantity of bricks* to the two sides of the pan without paying attention that w(a) and w(b) are different. So, $12 \times w(a) = 14 \times w(b)$ and $24 \times w(a) = 28 \times w(b)$. Since there are 27 bricks in D, Shay wants to infer that C weighs more than D. The reasoning here is hybrid between proportionality and additivity. At that stage, Shay compares relations between numbers of blocks in A-B versus in C-D, and as such acts according to the intention of the designers — to encourage S4 explanations. However, he is not able to undertake a full-fledged proportional comparison by himself (or with the help of Itay).

At that point, in 40e, the experimenter interrupts Shay. She does not let him express this correct conclusion probably because it relies on wrong reasons (Itay expresses this conclusion in 46i though, and consistently with our interpretation here, the experimenter does not react then). In 40e, she monitors Shay's reasoning by first maintaining a piece of reasoning that she thinks is fading out ("*you said that 10 blues and 12 oranges*") and also regulates further reasoning ("*And here how many blues are they*?"). In the structure of the interaction, the turn 47s is crucial, as this is the first time Shay computes a ratio: *if you reach here 20, you need four more, as if there were two tenths here*. This can be modeled as such:

If you reach here 20, you need 4 more	$w(10a) = w(10b) + 2w(b) \Rightarrow w(20a) = w(20b) + 4w(b)$
as if there were two tenths here	$\Rightarrow w(a) = w(20b+4b)/20 = w(b)+2/10w(b)$

This explanation is crucial. *It is a refinement of the emergent construct in item 7*: Shay not only considers the relative weight of bricks as he did during the interaction of item 7, but he also computes this relation as a ratio (two tenths). In 48e and 50e, the experimenter helps linking this ratio computed on A and B to C and D. In 56e, after Shay asks her about the ratio 2 tenths (of course without using the term 'ratio'), the experimenter invites Shay to focus on comparison between two tenths and the relation between C and D. Shay and Itay could have completed the last inference to correctly explain why C is heavier than D: $w(24a) = 24w(b + 0.2b) = w(24b) + 4.8w(b) = 28.8w(b) > w(27b)$. In 57s, Shay is very close to this full proportional piece of reasoning since the two tenths represent for him a factor:

Here there are two tenths	$w(a) = w(b)+2/10w(b)$
but if you take off…If you take off these 4,	
and you take off these 3,	$C' = C - 4\{c\}, D' = D - \{3d\}$
OK, this will be exactly…	$w(D') = w(C') - 0.2 \times w(C')$

Itay's intervention in 58i takes Shay back to additivity. However, in his last intervention (60i), he somehow sums up the different reasoning processes produced in the interaction by declaring, *This is it more or less, although here there are more boxes* the content of which we hypothesized to be '*{w(C) > w(D)}* even though {n(C) < n(D)}'. It is interesting to note the modality adopted by Itay in 60i ("although here"): Itay's final argument is hypothetical. Although the proportion finally agreed upon by the interlocutors in this sequence is not fully correct, a new co-constructed piece of reasoning emerges, and it is full-fledged proportional.

This emergence involves crucial ingredients: first the initial additive considerations, then the weighing that challenges first explanations, and the revision of the first explanations which leads to the use of S3-explanations that emerged in Item 7; then since the students realize that these explanations cannot explain the result of the weighing, the initiation of numerical proportional considerations; the students cannot complete them and regress to additive explanations, but the experimenter intervenes and monitors students' actions and reasoning processes. In summary, three contextual aspects of Item 10 mediated the emergence of the full-fledged proportional reasoning: (i) the design of the instruments — the configuration of the blocks encouraged certain strategies, (ii) the weighing — it challenged expected answers, and (iii) the scaffolding of the experimenter. Although Shay and Itay often completed each other in their interventions to co-elaborate a new strategy like in the case of Item 7, the new emergence is fundamentally different here, as these are the experimenter and the task itself that mediate the new emergence as a refinement of a previous one.

We turn now to the reasoning processes involved in the post-test. In the post-test, an experimenter invited Shay and Itay to solve Items 3, 4 and 8 individually. The social context in the post-test is different from the interaction phase of course, and includes the experimenter. We intended to observe whether Shay and Itay would capitalize on the pieces of reasoning that emerged in the interaction phase.

5.1 Shay's actualization of the S4 strategy in the post-test

We present here the propositional content of Shay's explanation. From an interlocutory perspective, this is a long *explanation* that Shay *asserts*:

It's impossible to know	{w(C) / w(D) = ?}
Since in B, there are more boxes than in A and it weighs more	since {n(B) > n(A)}V{w(A) > w(B)}
And in C and D where there is the same	{n(C) = n(D)}
So I don't have data to decide between these two boxes in C and D	⊃{w(C) / w(D) = ?}
Maybe, if there had been one more box in D,	{D' = D + {d}}
then I could have said that D weighs more than C:	⇒ { w(D') > w(C)}
But since they are the same,	{n(C) = n(D)}
I can't know.	⇒ {w(C) / w(D) = ?}

Shay initiates his explanation by linking the relations between the numbers of bricks in the two pairs of blocks, which is indispensable for the resolution of this task. This explanation is proto-proportional. Then Shay imagines another possible case in order to reason on it. This is a new block obtained by adding one more brick on D. This hypothetical case is not necessary here since Shay successfully solved item 8 by using proto-proportional explanations. However, Shay probably recalls a similar hypothetical case to solve item 10: He proposed to add one brick (and not 2 as proposed by Itay) to add to D, so that the relation between C and D would be equivalent to the relation between A and B to declare, "*We should have had one more box so that D would be equal to C*". It is also interesting to note here the role of modality ("Maybe", "if there had been", I could have said). Shay does not undertake any computation characteristic of full proportional explanations, *because it is irrelevant here*. It is probable that when he uses terms such as 'maybe', he estimates the values of 28/27 and of 31/30. Therefore, in this short episode, we can observe that Shay deploys and succefully actualizes here a piece of reasoning co-elaborated during the interaction session for item 10. *He adapts it* to item 8 to capitalize on relevant considerations only.

5.2 Itay's actualization of previously elaborated strategies in the post-test

Itay is quite fluent in solving item 3. He immediately draws the right conclusion and when the experimenter asks for explanations, he first sets explicitly the relevant premises (*Because you said that here A and B are equal, and here there is one more box*), expresses his doubt about his conclusion, then makes an inference pertaining to proportional reasoning (*Then I know that each box here (B) weighs more than a box here*), to conclude that D is heavier. Except for the doubt Itay expresses, he asserts very clearly the right answer while articulating S3 proto-proportional explanations.

We already indicated that Itay did not succeed in the pre-test and constantly deployed additive non-proportional explanations. Thus, the proportional explanations he deploys in Item 3 of the post-test clearly originate from the interaction. And indeed, we saw in Inter7 that Itay declared in 7i4b:

And if here it's the same, then B is heavier	$\{n(A) = n(B)\}$ *and* $\{w(B) > w(A)\} \Rightarrow \{w(a) < w(b)\}$

We saw that Shay and Itay were attuned. In 11s Shay continued Itay's reasoning:

We don't have data on how much each box weighs	$w(b) - w(a) = \Delta,\ \Delta = ?,\ w(D) - w(C) = ?$

In 13s, Shay concluded with the help of the experimenter:

Impossible to know	$\Rightarrow w(D) = w(C) \vee w(D) - w(C) = ?$

The turn 7i2 in Itay's Item 3 in the post-test looks very much like 7i4b in Inter7:

Then I know that each box here b. weighs more than a box here	$\{n(A) = n(B) + 1\}$ *and* $\{w(A) = w(B)\} \Rightarrow \{w(b) > w(a)\} \Rightarrow \{w(d) > w(c)\}$

From this inference, Itay concludes in 9i:

Yes, so D must be bigger	$\{n(C) = n(D)\} \wedge \{w(d) > w(c)\} \Rightarrow \{w(D) > w(C)\}$

Like Shay in the post-test, Itay showed in item 3 that he could use adequately pieces of reasoning co-elaborated during interaction in the post-test.

Table 3 shows a very different picture for Item 4: Itay asserts *you can't know* in 3i but cannot explain clearly his conclusion in spite of the experimenter's (multiple requests for) clarifications (4e, 6e, 8e, 10e1, 10e2, 12e1, 14e). Itay does not succeed to draw the simple inference $\{w(A) < w(B)\}$ and $\{n(A) = n(B)\} \Rightarrow \{w(a) < w(b)\}$. Rather, he declares, "*It's like there, it's impossible to know what is the weight of the boxes*" in 5i2 that echoes Shay's assertion that *it is impossible to know* in 13s at the end of the interaction to solve Item 7. Item 7 in the interaction and Item 4 in the

Table 3. Shay's pre-test (Item 6)

Sequential	Illocutionary force		Propositional content
	Type	In context	
1Shay1: In my opinion, C and D are equal	A	Response	{w(C) = w(D)}
1Shay2: because A is heavier than B	A	Explanation	{w(A) > w(B)} ⊃ {w(C) = w(D)}
1Shay3: because it is possible that it is because there are more boxes	A	Explanation	{n(A) > n(B)}
1Shay4: So, C and D, because they have the same number of boxes and the same structure	A	Elaboration	{n(C) = n(D)} ∧ {structure (C) = structure (D)}
1Shay5: So it is possible that C and D are equal	A	Conclusion /response	w(C) = w(D)}
2Exp: Is it possible?	Q	Req. Clarif.	{w(C) = w(D)} = ?
3Shay1: It is possible	A	Response	{w(C) = w(D)}
3Shay2: because we can't know	A	Explanation	{w(C) / w(D)} = ?
3Shay3: because we know that A is heavier than B but in A there are more boxes	A	Elaboration	{w(A) > w(B)} ∧ {n(A) > n(B)}
3Shay4: we may think of a situation where blues are heavier than yellows and we don't know how much heavier they are	A	Elaboration	{w(b) > w(a)} = ?
3Shay5: so, we can't know	A	Conclusion/ response	{w(C) / w(D)} = ?

post-test resemble since in both tasks {n(D) = n(C) – 1}; Itay uses this similarity to adopt exactly *the same conclusion* as in Inter7, "*here, you can't know*" (3i). Even the experimenter's objection, *Each green box in A weighs more than each yellow box in B* whose content is *{w(A) > w(B)} and {n(A) = n(B)}* ⇒ w(a) > w(b)}(16e), and which should have easily led Itay to use {w(a) > w(b)} in comparing C and D, was not exploited by Itay. The many attempts of the experimenter to apply the inference {w(a) < w(b)} in the comparison between C and D all failed (turns 21–22, 24–25, 26–27).

In conclusion, it seems that the construction that Itay contributed to elaborate in the interaction session is well actualized by him in item 3 in the post-test. In the similar case of item 4, Itay uses the same inferences, almost verbatim, but in this case it is inadequate. In Post8, Itay gave a correct answer. But there also, his behavior is ambiguous, as it is quite similar to item 7 and the solution is the same (it is impossible to decide) and there is no trace of the adaptive reasoning exhibited by Shay that would not have denoted the blind repetition of previous answers.

6. Status of the observed behaviors: Four types of constructs

The analysis of our data helps understanding the different meanings of a successful performance (immediate insight, blind or mastered repetition of a previous individual action, blind or mastered repetition of a previous collective action, new successful elaboration). The close analysis of the phase of interaction illustrates clearly that, although the experimenter had been asked to remain as neutral as possible, this is not just a dyadic interaction between two students sustained by an adult, but a triadic interaction with an experimenter who has a very important and active socio-cognitive role, beyond the key one of presenting an appropriately designed task: setting rules for collective argumentation, reframing the roles, allowing for the use of a measurement instrument at the proper moment of a conversation, prompting, reminding the instructions, requiring an explanation, asking for clarifications of a doubt, giving moral support one of the debaters, triggering the students' reasoning by a question, scaffolding a new kind of answer, etc. Although the experimenter was less active in the pre-test and the post-test — for example, in the post-test, Shay and Itay generally expressed a long argument to solve the item without any intervention, it happened that she was very active (for example for Item 4 with Itay).

What is then the status of the observed constructions? Is it a compliance with the conversational request of the experimenter or of the partner without understanding the topic, or rather a deeper engagement towards the goal of the experimenter witnessing some autonomous proportional reasoning from the side of the student? In our data, we never found the experimenter asking 'fishing questions' to obtain explanations she wanted to hear. During the phase of interaction, students raised doubts, expressed oppositions and articulated arguments; they actively engaged in collective argumentation. Also, they modified the illocutionary force of arguments they previously expressed (e.g., Itay's expression of a doubt in the pre-test, twisted to a critique to Shay in the peer interaction). Such behaviors point at some kind of autonomy. Yet, would the participants have been engaged in these proportional reasoning processes if the experimenter had not intervened at key moments? So, we are observing participants who display some kind of autonomy and simultaneously are taking part in a collective reasoning. Hence, we suggest adopting the term *emergent constructions* to designate construction as the co-elaboration of a restructuration (i.e., of new coordinations of operations leading to new concepts) towards the goal, in the present case a step towards a proportional reasoning strategy. *Emergent construction in interaction* is then a case of *hic et nunc* restructuration during interaction. It is the product of the present socially situated efforts of the subject to respond adequately to the socio-cognitive demands of the interlocutors and of the task. Emergent construction is then a central event deployed at a collective level. The two examples of emergent construction were quite different: for the first one (item 7), the peers engaged in an argumentative activity among them and although the experimenter helped argumentation remaining fluent, the students were quite autonomous. For item 10, peers could not progress until they used the balance, which denied their hypotheses. Thereafter, the experimenter scaffolded the co-construction of a new strategy. We suggest designating the first kind as *non-guided emergent construction in interaction*, and the second one *guided emergent construction in interaction*.

The distinction between guided and non-guided emergent construction is fundamental. It points at two different situations: when emergent construction is guided, the experimenter monitors the interaction between peers, tracks the elaboration of ideas and intervenes when she thinks that she may help developing an inference. The guidance is directed to construction. As for the unguided case, the experimenter is still present and sometimes intervenes, but her intervention concerns keeping students focused to reach a common solution. In both cases, the task itself affords the elaboration of certain explanations. This is clear in the guided case, when weighing contradicts the expected conclusions (expected for the students and the researcher) and invites peers to compare ratios. In the case of the unguided emergence of the S3 strategy to solve item 7, the role of the task is indirect: for example, peers know that they will eventually weigh blocks and this constraint invites them to engage in a reasoning process. Theorists may then argue that what we called unguided emergent construction is, to a certain extent, guided. This is true but this kind of guidance is totally different from the guidance in the first case: no prompt concerning proportional reasoning is purposely provided by the expert adult to the peers.

We suggest that the distinction we propose between unguided and guided emergent construction in interaction is compatible with observations made by Howe and colleagues (e.g., in Howe et al. 2000) when studying the effects of peer interaction on *conceptual change* in physics. They showed that discussions around conceptual knowledge are sterile unless integrated with procedures supported by the task — complying with a hypothesis testing procedure, and by the experimenter — asking peers to reach consensus during their discussions. In Howe and colleagues' words, this is a procedural rather than a conceptual guidance. We prefer keeping the term unguided to describe this situation for two reasons. First, guidance in *unguided emergent construction* is not about the object of learning, proportional reasoning. Secondly, we can conceive of cases in which even discussions among peers are not guided even procedurally, although according to research literature on conceptual change, conceptual change in such conditions is very rare.

An important specific contribution of the present work concerns conceptual change in proportional reasoning. We showed the role of collectivity in unguided and guided emergent construction. For both constructions, taking into consideration all components/comparisons was too difficult for the individual. Collectives coordinated actions through argumentation with the help of which arguments were distributed among participants. *The complexity in high-level proportional reasoning is tackled collectively, thus enabling division of work towards conceptual change*.

Are emergent constructs ephemeral? Will they be forgotten later on? The answer to this question has socio-cultural as well psychological dimensions: on the one hand, it depends on the opportunities opened to the learner to stabilize this 'anecdotic' experience in something 'known' that can be referred to. In school, the teacher opens opportunities by choosing *successive* tasks and by directly reminding the learner what was done during the previous task or by giving the student a similar one. On the other hand, it depends also on the role taken by the learner in the collective performance that emerged during the interaction. The question then is whether and how the co-elaborated mental activity affects the actions of the individuals in a further social activity designed to encourage the use of this new outcome. In the present experiment, we administered the same task in the post-test and saw that the individuals capitalize on S3 and even S4 strategies previously elaborated.

But what is the psychological status of this 'capitalization'? Are the subjects of this experiment just making a straightforward restitution of the responses they have reached, maybe without really understanding them? Or do they enact a new understanding previously internalized? To address this question we undertook a fine-grained analysis of the interactions during the post-tests, in which we considered the micro-reconstruction of the two students while re-capturing elements previously co-constructed. We found that sometimes, this micro-reconstruction was well adapted (i.e., an adequate response to the task demands accommodating to its specificities) and that sometimes it was not (i.e., the response seemed to be a repetition of a behavior addressing the previous situation rather than the present one). An adequate terminology that differentiates between these two types is then necessary. We suggest designating the case of mal-adaptation as *retrieved construction from interaction* (to convey the idea that something has been learned during the collective action but remains at the surface of the psychological functioning of the person as something somehow external and rigid — not grounded into a restructured understanding). The opposite is a successful adaptation. Yet, the status of such a successful use of what has been constructed is very often ambiguous, since success may be the result of chance hence being only *retrieved construction from interaction*. In this case, the re-use is rigid, and unmodified. The disambiguation vanishes if the student adapts to the new situation; we call this phenomenon *continuing construction from interaction*. *Continuing construction* consists then of the emergence of a new construct subsequent to a restructuration (as shown for Shay in item 8 of the post-test) which the individual is seen capable of *after* having participated in a collective performance. *Retrieved construction* shows the actualization of a competence as the mere repetition of a previous collective behavior (see the case of Itay). *Retrieved construction* seems to echo Piaget's notion of 'learning in a restricted sense'. While 'learning in a broad sense' is what can be observed in *emergent construction* and *continuing construction*, the transformation observed concerns mental operations and their use is modulated to the circumstance. *Retrieved construction* concerns the rigid adoption of a response (without being able to check its relevance). We can illustrate this with Itay's post-test: in item 3 Itay seems to act in a competent way but in item 4 the same hypothesized competence is not actualized. *Retrieved construction* means learning in a restricted sense, that of a local response, one which is not understood in its operational value.

The example that illustrated the case of *continuing construction within interaction,* showed that Shay could *make relevant* an inference drawn previously in the interaction to construct a new conclusion for item 8 in the post-test. In that case, the fact that Shay could make relevant an inference drawn in a former situation in a later context, and could use it in a new construction, suggests that during the interaction or after it, the psychological functioning of the subject has changed. However, such a process of adaptation is not always necessary even when the psychological functioning of the subject has changed. It depends on the task since the mere *reproduction* of a previous action may sometimes suffice to perform the task. The reproduction of an action in a similar task is then always ambiguous: is it a mere blind repetition or has the subject changed his or her cognitive functioning? Does the subject feel obligated to capitalize on recently constructed strategies, explanations, etc., in the task in which he or she was engaged and then just 'feeds them back' to his or her interlocutor? Or has this previous experience led him or her into a reconsideration of the responses given, and has this reconsideration fostered a new understanding? The change in the cognitive operatory processes is only revealed in later tasks, provided that these tasks are adequate to evidence the change. Further, if such a change occurs, it will be perceived by the external observers as *emergent construction* or *continuing construction* but not necessarily by the subjects themselves because 'the consciousness of having constructed' is something different than 'constructing'.

A precision concerning the term 'continuing' is necessary. Continuing construction is observed through the recurrence of emergence, but the observation does not tell us whether the recurrent emergence results from reflection between activities — here interaction and post-test, or from the participation to the new activity — here the post-test. The term 'continuing' conveys this ambiguity: On the one hand, the new emergence evidences that a past emergent activity was accounted for; on the other hand, this is a new emergent construct, whose end is only visible, and whose initiation may have begun before the activity observed.

We claimed at the beginning of this article that we adopt a conversational perspective to learning. And indeed, although in this experiment the trace of past constructions was sometimes considered to decide the status of new ones, this decision basically relied on how talk deploys in conversation in the present. Past was referred to through the comparison of interlocutory forces or through comparison between propositional contents, not through any psychological (indirect) inference. The variability of strategies that appeared in Schwarz and Linchevski's study recurred in the present one: the number of participants — two in the pre- and post-test, three during the interaction phase, and the guidance of the experimenter were not uniform. Consequently, quite understandably, the elaboration of strategies, the outcomes of these activities, could fluctuate. Finally, we could observe the importance of the design: although nobody elaborated a full-fledged proportional strategy in the prior study, a new item, designed to challenge expected answers, led to a discussion in which the experimenter helped students elaborating a S4 for the first time.

We have already explained that the constructions occurred according to an apparatus we set: the post-test was intended to trigger actualization, item 10 to initiate the emergence of a new strategy, etc. As such, this study does not seem to have any relevance to developmental issues. However, developmentalists such as Siegler have already compared microgenetic and age-related change (Siegler and Svetina, 2002) to show that recurrent learning processes initiated in the laboratory, model in certain cases development. Since participation to a succession of similar activities is commonplace at school, we may speculate that some of the successions of constructions we identified are relevant to development. For example, it seems that the succession unguided — guided emergent constructions in interaction in which two new strategies are elaborated has great potential for development if it recurs, since it integrates autonomy of the learners with guidance. Additionally, the alternation of emergent and continuing or retrieved constructions seems a promising direction from a developmental point of view. But obviously, a vast research program is needed to investigate this untapped and exciting domain.

7. General discussion and concluding remarks

In the present experiment we undertook a step-by-step description of the microgenesis of the understanding of two students within successive conversations. We showed that item 10 afforded the elaboration of proportional explanations not present so far. We interpreted that the success in solving item 10 originated from the balance that provided challenging feedback to the hypotheses expressed so far and from the active role adopted by the experimenter. We observed different types of constructions developing through the successive activities, and the role of context (balance, peers, experimenter, rules of conversation around the task) in these constructions. We intentionally used the term 'construction' in place of 'learning'. The term 'construction' reflects our methodological approach that was based on the analysis of conversations. The constructions we identified were elaborated *hic et nunc*, in the course of conversation. We can call these constructions processes as learning processes, but describing these types of co-construction as learning processes challenges the view that changes of strategies characterize only *individual* learning: in the present study, we showed that the elaboration of new strategies clearly appears as a collective construction in which the role of the experimenter, which was neglected in the first study, is shown as decisive at some moments. As a consequence we should revisit our previous understanding of three phases of pre-test, treatment and post-test to measure the individual's cognitive gains from an unmediated activity. The detailed analysis of the protocols has instead revealed the three phases as social interactive events: in the pretest the subject is not performing alone but within a setting in which the adult sets the task and the tempo, guiding by her expectations, interventions and task demands the child's strategies; the interaction phase may be described as a kind of triadic interaction involving a peer and an experimenter, and we have seen how important the experimenter's role is. In the post-test, again the subject is not in a social vacuum but has in mind his former partners' voices when meeting again the same experimenter and the same task demands, and having to take part in a conversation that unfolds between two active persons again, and not with a mute and neutral non-ego! Such a departure from traditional approach to study learning echoes Perret-Clermont's previous theoretical and methodological considerations (1993; Perret-Clermont and Carugati 2001; 2004).

To what extent the purpose of this study, observing learning as it emerges in the context of the laboratory, is relevant to contexts in which learning is not the object of research (only), but one of its main objectives? Scientists that reflected on the contribution of the school context to learning and development have focused on a reconciliation between epistemological-constructivist and ontological-situative accounts of learning. For example, Hiebert et al. (1996) called them respectively functional and structural perspectives on understanding. The first "focuses on the activity of the classroom," the second "on what students take with them from the classroom" (see also Greeno 1997; Greeno and TMSMTAPG 1998; Cobb and Bowers 1999). However when it comes to actual fine-grained descriptions of learning events, reconciliation is not clear.

We believe that the identification of the four types of learning processes in the present context may be useful for school context. Relevance concerns first a lack in the present experiment, a lack that stresses what the school does or should do: In the course of their participation in school activities, students not only succeed or fail in tasks but they are explicitly given feedback on their performance which is assessed by the teacher, appraised or not, and the recognition of teachers impinges on the way students consider the value of their responses and even on the way they see themselves. Good answers are usually "institutionalized" as such by teachers; in other words, by stating that yes, the student is now giving the proper answer, the teacher also makes visible what is the valid knowledge that the school institution wants to transmit. Let us take the example, in the present experiment, of the interaction during which a full-fledged proportional strategy emerged and in which the expert adult kept a "neutral" (and not a normative) role. In their study on proportional reasoning, Harel et al. (1992) showed that among junior high-school students, the level of strategies in proportional reasoning fitted general level in mathematics. In other words, when Shay and Itay, with the help of the experimenter, co-elaborated a S4 strategy, they performed a task that *characterizes* a group to which they did not belong. This performance was outstanding but the experimenter did not provide any feedback that alludes to this fact, and we bet that as a consequence, Shay and Itay might not have realized that they had become better in mathematics, nor have they (seemingly) become conscious that what they were learning concerned "proportions". The school context is then supposed to provide this necessary social recognition of what is learned and of it being learned (through corrections of tests with proper explanations, congratulations of the teacher, assignation to a group of higher achievers, etc). This social-institutional validation is absent in the present study. In fact, more precisely, this validation is implicit in the present study: when the expert asks peers to stop their discussions in order to check their hypotheses on the balance, this is because she estimates that the time has come to provide a negative feedback (for 'wrong conclusions'), or a confirmation (for 'right conclusions'). Also the fact that the experimenter-adult goes on accompanying the conversation is an implicit sign for the students that what they say is valuable. However, in the present context, the social-institutional validation has not been controlled and obviously is never explicit. We suggest that, by not controlling for the social-institutional validation implicit in the adult's acceptance or not of the subjects' responses, this experiment stresses an individualistic (or "social-vacuum" like) epistemological perspective.

Laboratory is traditionally viewed as allowing scientists to isolate variables to be studied, and cognitive psychologists have often seen the laboratory as a place to neutralize the role of context in studying psychological processes — at the cost of forgetting that the laboratory is a social context! We identified a rich context in which the experimenter played a crucial role in the very objects of the study, learning processes. We did not study the development of the self and the relations between the sense of self-value and the possibility to perform well or to learn. Nor did we investigate the risks of learning for the self (Pain 1981; 1985). Such studies would help completing our understanding of learning processes as they occur in the laboratory and in the school context. Anyway, we suggest that the typology obtained in the present study in a context which is less complex than the context of the school provides helpful tools to understand learning in the school context.

Notes

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1. Vanderveken (1990) defined the six first illocutionary forces. We added the questioning force which is common in the framework of problem solving. Typically this framework makes it difficult to express a declarative force — a speech act that modifies the reality. And indeed, the protocols included only assertive, questioning, committing, expressive, permissive, and directive forces.

2. The formalization {D + X} refers to 4Sb in which Shay pointed at block D and claimed, "something is missing here". From this turn onward, {D + X} is the object of the reasoning of Shay and Itay. This interpretation is confirmed by the following turns in which the object {D + X} is necessary to apprehend this sequence of turns.

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