The interplay of micro- and macro-scaffolding: An empirical reconstruction for the case of an intervention on percentages

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Abstract. Micro-scaffolding is an important *local* phenomenon on a micro-scale of teacher-student-interactions. However, the idea of supporting students to move forward in their zones of proximal developments requires a sound *global* conceptualization of the intended learning trajectories. This article focuses on the trajectories towards percentages, and investigate how micro-scaffolding depends on aligning students' learning pathways to these intended learning trajectories (designed in macro-scaffolding). A qualitative study was conducted in a series of design experiments. In the process of analyzing 590 minutes of rich video data with respect to the interplay between micro-and macro-scaffolding, a new analytic procedure, trace analysis, is developed and applied to the analysis. One central outcome of this study is the relevance of a key characteristic of effective micro-scaffolding, namely reference to a hypothetical learning trajectory as macro-orientation.

1. Introduction

Interactional micro-scaffolding is increasingly discussed as an important approach for *locally* supporting students' learning pathways towards language learning and conceptual learning in mathematics classrooms (Gibbons 2002; Smit et al. 2013; Wessel 2015). Although the main idea to support students' progressions includes the synergy between teachers' scaffolds, designed materials and activities (as emphasized for example by Tabak 2004), the underlying learning trajectories often stay implicit and are rarely taken into account systematically in the research on micro-scaffolding. So far, only a few empirical insights exist in the interplay of micro-scaffolding and macro-scaffolding, i.e. aspects of scaffolding that require *global* consideration of hypothetical learning trajectories in the design of the intervention.

The study reported in this article empirically investigates how micro- and macro-scaffolding *depend on each other*. In order to pursue this research direction, the teaching and learning processes are analyzed in an exemplary intervention about percentages for seventh graders with a low German second language proficiency and difficulties in percentages. The intervention intertwines a conceptual and a lexical learning trajectory towards percentages to support students to acquire a conceptual understanding of percentages and lexical means to communicate about them. By a qualitative in-depth analysis, the processes of micro-scaffolding are investigated thoroughly in their relation to macro-scaffolding.

The article starts by sketching the theoretical background of this research and the underlying conceptualizations (Section 2), followed by the research context of the concrete intervention on percentages (Section 3). After reporting on the methodology of the design research study (Section 4), selected research outcomes of the qualitative investigations are presented and discussed (Section 5 and 6).

2. Micro-scaffolding and macro-scaffolding – state of research and research gap

2.1 Origin and variety of micro-scaffolding

The main idea of scaffolding can be traced back to Vygotsky's classical construct of the zone of proximal development (cf. Gibbons 2002, p. 10). The notion scaffolding itself is first defined by Wood, Bruner and Ross (1976) in the context of problem solving for kindergarten children as enabling a

"novice to […] carry out a task […] beyond his unassisted efforts. This scaffolding consists essentially of the adult 'controlling' those elements […] initially beyond the learner's capacity, thus permitting him to concentrate upon […] those elements […] within his range of competence" (ibid., p. 90).

The authors identify scaffolding practices such as prodding (keeping the learner in pursuit of an objective), pointing out discrepancies, modeling the solution, etc. These early ideas mainly concern scaffolding given by a more knowledgeable person (mother, teacher or …) in a one-on-one interaction at the micro-level, thus it is termed *interactional micro-scaffolding* (e.g. Hammond & Gibbons 2005).

During the last 40 years, the construct of scaffolding has been extended to different learning contents (cf. the surveys of Lajoie 2005; van de Pol et al. 2010; Reiser & Tabak 2014) and settings, especially to language learning in multilingual classrooms (e.g. Gibbons 2002; Hammond & Gibbons 2005). For adopting to different conditions, the contexts of scaffolding have been extended from one-on-one interactions to whole-class scaffolding (Smit et al. 2013) and to scaffolding by technical tools or peers (e.g. Lajoie 2005). This paper discusses small-group scaffolding in multilingual groups with a double focus on mathematical concepts and language learning.

Van de Pol et al. (2010) make generalizations of various conceptualizations for scaffolding and suggest criteria for teacher-learner interaction over time as a common core (Figure 1). The teacher offers a lot of support at the beginning, and successively fades out this support in order to transfer the responsibility to the student. In each phase, the support is contingent (i.e. responsive) to the students' current stage of learning. Contingency requires diagnostic strategies for noticing students' stage of learning as well as scaffolding strategies for concrete support.

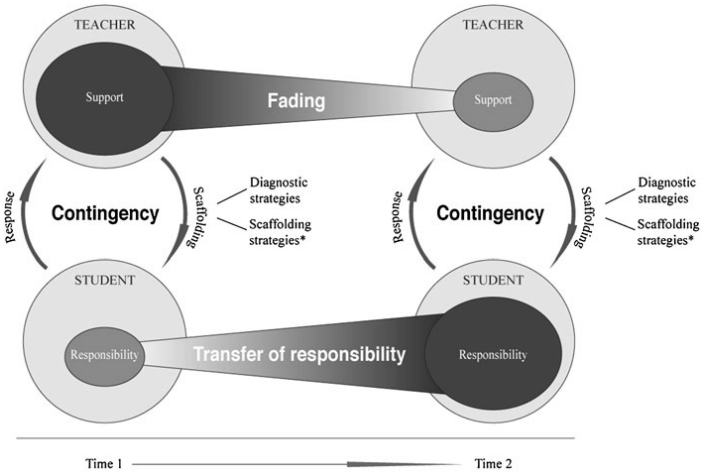


Fig. 1 Model for scaffolding (van de Pol et al. 2010, p. 274)

As this study deals with mathematics and language learning, the underlying theoretical framework refers to the specific key characteristics developed by Smit et al. (2013, p. 817ff) for the case of whole-class scaffolding in multilingual mathematics classrooms. Compared to van de Pol et al.'s (2010) work, Smit et al. shift the emphasis towards the previously mentioned diagnostic strategies by identifying the following key characteristics for scaffolding:

(I) diagnosis (i.e. noticing students' current zone of proximal development),
(II) responsiveness (i.e. adaptivity to students' current and possibly subsequent zones), and
(III) handover to independence (the transfer of responsibility to the students and fading out).

2.2 Macro-scaffolding in its interplay to micro-scaffolding

Various designers have mentioned the necessity to complement the interactional micro-scaffolding by other resources (an early example is given by Puntambekar & Kolodner 1998, who describe scaffolding as *distributed* over several tools such as interactional moves, tasks, diaries, software tools, etc.).

For the specific case of scaffolding language learning and subject matter learning in multilingual classrooms, Gibbons (2002) and Hammond and Gibbons (2005) emphasize the need for a longer-term macro-scaffolding in the lesson design. They define *macro-scaffolding* as comprising the reconstruction of students' prior experience, the learning goals for sequencing intermediate learning goals and support means, and instructional tasks along the intended learning trajectory (Gibbons 2002, similarly in Smit 2013; Smit et al. 2013 as 'offline layer of scaffolding'). Specifying learning trajectories is not only necessary to define and to reach mutual zones of proximal development in an interaction, but it is also the core of an intervention in subject matter learning (Confrey 2006). In this article, the term 'trajectories' is used for the hypothetical intended trajectories (conceptualized as wider corridors rather than narrow trajectories, cf. Confrey 2006) and 'pathways' for the individual student's empirically reconstructed trajectories.

In a certain way, all conceptualizations of micro-scaffolding require at least a vague specification of a learning trajectory with reference to responsiveness, the zone of *proximal development*, and students' *increasing* capabilities (argued by Tabak 2004). However, for the empirical research on scaffolding, these intended learning trajectories are sometimes not made explicit a priori, or rarely systematically addressed in the research on micro-scaffolding, as shown in the survey by van de Pol et al. (2010). Some authors even criticize the extension to macro-scaffolding as an unnecessary over-generalization of the scaffolding construct (summarized by Smit et al. 2013, p. 818).

In contrast, Hammond and Gibbons (2005) plead for the need to systematically account for the learning trajectories in the design of intervention because the intended students' learning cannot be achieved on the micro-level alone without a systematic offer of suitably sequenced activities, i.e. without macro-scaffolding. Also, Smit (2013) and Wessel (2015) include macro-scaffolding in their lesson designs. Both show that responsiveness requires teachers' reference to an intended learning trajectory which is often embedded in the design of tasks.

In spite of the implicitly or explicitly acknowledged role of macro-scaffolding in tasks design and in teachers' actions, few studies investigate the interplay of micro- and macro-scaffolding empirically. Specifically, little is known so far about how micro-scaffolding supports macro-scaffolding and to what degree micro-scaffolding moves relate to the various parts of the intended learning trajectories. Hence, a fourth key characteristic of micro-scaffolding that needs to be taken into account by designers, tutors and especially by researchers is made explicit here:

(IV) provides reference to an intended learning trajectory as the macro-orientation for micro-scaffolding moves.

In a local perspective, this characteristic (IV) is already subsumed in Smit et al.'s (2013) characteristic (II), *responsiveness*, which asks for the local direction of change to be in line with the learning trajectory (e.g. the tutor asks students for the subsequent steps while solving a problem). So far, most designers seem to adopt a more global perspective of the complete learning trajectory, but the word "independence" in the term *handover to independence* (characteristic III) does not adequately reflect the learning goals of this criterion. Additionally, the designers' focus alone is not sufficient when most research studies mainly focus on the local directions of change. The request to systematically take into account the global progression of the learning trajectory has methodological consequences for research as this additional perspective calls for new methods to investigate the teaching and learning processes (discussed in Section 4.2).

2.3 Scaffolding means and contents

Van de Pol et al. (2010) suggest differentiating the diverse empirical studies on micro-scaffolding according to their *contents* (which they call scaffolding intentions) and *means*. Among the means, they distinguish different kinds of scaffolding strategies such as modeling and questioning (cf. Section 5.1). With respect to macro-scaffolding, elements such as instructional tasks and visualizations are counted as scaffolding means, and both of them play a major role in the intervention of this study (cf. Section 3). For reasons of clarity, the notion *scaffolding moves* is used here as the unit of analysis for teachers' oral micro-scaffolding strategies.

Furthermore, van de Pol et al. (2010) distinguish scaffolding studies according to three kinds of scaffolding contents: metacognitive activities, cognitive activities, and affects. It is astonishing that studies on scaffolding subject matter concepts (like percentages) or language learning are not included in their survey given their importance in multilingual subject matter classrooms (cf. Hammond & Gibbons 2005; Smit 2013; Wessel 2015).

Although scaffolding can address all areas of language learning (lexical, semantical, grammatical, pragmatical, and discursive, cf. Morgan et al. 2014 for a wider view), the efforts on language learning in many mathematics classrooms mostly focus on the *lexical area*, i.e. on acquiring lexical items like words and phrases from the technical mathematical register. Based on this focus, instructional approaches with word lists, sentence frames or vocabulary posters have been elaborated and disseminated (e.g. Wessel 2015 for an overview). In this tradition, a *lexical learning trajectory* can be specified that aims at extending the students' individual lexicon (i.e., vocabulary students actively use or understand).

But as many linguists have emphasized the necessity to embed a lexical learning trajectory in other areas (e.g. Schleppegrell 2004). Rather than acquiring only words and phrases specific to mathematical concepts, students need to construct the meaning of these mathematical concepts (*semantic area*) and

learn to apply these concepts to related problems and the purposes behind these applications (*pragmatic area*), as Freudenthal has already emphasized (1983). The learning contents in the semantic and pragmatic areas refer to the subject matter learning content of mathematical concepts, which is hereby subsumed in the *conceptual learning trajectory*. Although discursive aspects are also always present, this study focuses on the reflection and investigation of macro-scaffolding with respect to the systematic combination of conceptual and lexical learning trajectories. This focus allows to study scaffolding in a subject matter intervention for second language learners, a context that requires more attention as Smit (2013, p. 26, 106) has emphasized.

So far, little empirical insights exist regarding the role of micro-scaffolding in the interplay of conceptual and lexical learning trajectories. Before presenting the research methodology for investigating it, the research is situated in its context of a specific intervention towards percentages.

3. An intervention on percentages as research context

„Because the appearance of scaffolding depends so heavily on the context, it is of great importance in future scaffolding research that the context be specified into great detail.“ (van de Pol et al. 2010, p. 286). Following this claim, this section carefully presents the context of the present research.

This study is part of a larger design research project that combines the conceptual and lexical learning trajectories in an intervention towards percentages (Pöhler & Prediger 2015). In this section, underlying principles and their realization are presented as far as they are required for the research on the interplay between micro- and macro-scaffolding.

3.1 Conceptual learning trajectory towards models for percentages

Percentages is chosen as the topic of this design research due to its major role in middle school mathematics and everyday academic life. Many empirical studies have shown students' difficulties with percentages (e.g., Kouba et al. 1988; Lamon 2007; Parker & Leinhardt 1995). Parker and Leinhardt (1995, p. 473ff) suggest four reasons for students' difficulties; the first three reasons focus on conceptual understanding: (1) the complexity of the mathematical content (covering the coordination of percent, amount, and base as core concepts), (2) the diversity of relations that can be described by percentages (parts of wholes, comparisons, changes, etc.), and (3) these relations, except for part of whole, are often not explicitly treated in the curricula. Reason (4) involves the language challenges in cracking word problems with percentages, as the relevant mathematical relations are often "invisible in the language" (ibid, p. 473). These findings call for the need to consider the intertwinement of students' lexical and conceptual learning pathways, especially for students with low language proficiency who significantly underachieve in percent tests (Pöhler, Prediger, & Weinert 2015).

An instructional approach for conceptual macro-scaffolding should support students' development of conceptual understanding (i.e. student's mental models for mathematical concepts and their connections) in a *conceptual learning trajectory* starting from everyday experiences towards sustainable and flexible models of mathematical concepts.

A well established instructional approach in mathematics education research that has elaborated these ideas for a long time (without naming it conceptual macro-scaffolding) is the Realistic Mathematics Education approach (Freudenthal 1983; Gravemeijer 1998; van den Heuvel-Panhuizen 2003). In RME, the hypothetical conceptual learning trajectories are constructed starting from imaginable context problems which allow students to re-invent mathematical concepts. Thereby they mentally construct their meanings in a guided process of emergent modeling, first as *models of* context problem situations, later as *models for* abstract mathematical concepts (Gravemeijer 1998). One central design principle in RME is the level principle according to which a hypothetical learning trajectory is to be sequenced over several levels of increasing deepness of understanding. These levels include a *situational level*, "where domain-specific, situational knowledge and strategies are used within the context of the situation", a *referential level*, "where models and strategies refer to the situation described in the problem", a *general level* "where a mathematical focus on strategies dominates over the reference to the content", and a *formal level* "of formal mathematics, where one works with conventional procedures and notations" (Gravemeijer 1998, p. 286f). After achieving these levels, students should be able to apply the acquired concepts to new problems in other contexts.

A convincing conceptual learning trajectory to percentages within the RME context has been presented by van den Heuvel-Panhuizen (2003): Students create a percent bar (cf. Fig. 2) as a *model of* situations of free parking lots and then further develop it into a *model for* concepts (such as base, amount, and rate) in multiple contexts. The percent bar allows students to structure the relations between the concepts by its double scale that supports the underlying proportional reasoning (and is therefore applied as a structural scaffold). The macro-scaffolding design underlying the present study includes adaptions to the central elements of van den Heuvel-Panhuizen's learning trajectory. These adaptations include a shorter start of the learning trajectory and other contexts, and systematically relating the adapted conceptual learning trajectory to the lexical learning trajectory (cf. Section 3.3 and 3.4).

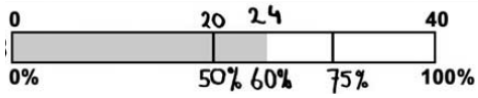


Fig. 2 Percent bar in a conceptual learning trajectory to percentages (van den Heuvel-Panhuizen 2003, p. 22)

3.2 Lexical learning trajectory towards percentage vocabulary

Students with low second language proficiency often develop weaker conceptual understanding than their more language proficient peers (cf. Pöhler et al. 2015 for percentages). This empirical finding can be traced back to the limitations in the academic school register (Schleppegrell 2004; Cummins 2000), especially in students' processes of meaning construction (Prediger & Wessel 2013).

This is why the design approach adopted here underpins the conceptual learning trajectory by a lexical learning trajectory, leading from students' everyday resources via the academic school register towards the technical register (Pimm 1987) and then back to academic school register for an extended reading vocabulary (cf. Fig. 3), with a strong focus on developing meanings for the introduced concepts and relations (Prediger & Wessel 2013; Pöhler & Prediger 2015):

- The learning arrangement must provide opportunities to activate *students' individual resources*, mainly in the everyday register (e.g. 'this here' or 'what we pay' for amount).
- In the intended conceptual learning trajectory, the context of the situational and referential level requires vocabulary for constructing meanings. The words and phrases that grasp the relations and meanings (e.g., 'new price' to describe the amount and 'the part of the new price from the old price' to explain the rate in percent as part of a whole) mostly belong to the academic school register and are subsumed under *basic meaning-related vocabulary* (Wessel 2015).

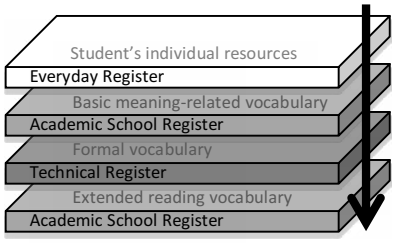


Fig. 3 Levels for a lexical learning trajectory (Pöhler & Prediger 2015)

- In the next step, *formal vocabulary* can be introduced for transcending the first context (e.g. base, amount, rate which are more formal in German: Grundwert, Prozentwert, Prozentsatz). The formal vocabulary vocabulary is the first in the focus of lexical scaffolding, but it needs to be complemented by meaning-related vocabulary.
- Once conceptual understanding is achieved, the initial contexts must be extended to further problems which students encounter in their textbooks, assessments, and out-of-school readings, such as newspapers. These further lexical challenges with (possibly synonymous) expressions reflecting the learnt mathematical concepts are subsumed in the so-called *extended reading vocabulary*, which goes beyond Wessel's (2015) framework and is not considered in this study.

3.3 Intervention linking the two learning trajectories

The coordination of the levels of the conceptual learning trajectory towards percentages (the first column) and the lexical learning trajectory (the third column) is reflected in the row structure of Table 1. The conceptual learning trajectory starts with constructing meanings and inventing strategies for the problem types "find the rate" and find the amount" on Levels 1 to 3 following Gravemeijer's (1998) levels, This happens before students are introduced to a third type of problem, "find the base". At Level 4, these three types of problems are enriched with other problems (e.g., "find the base after reduction") before students work on other more complex problems. As this study has its focus on Levels 1 to 3, the higher levels are not relevant here.

A typical challenge in coordinating the lexical and the conceptual learning trajectories is their mutual dependence (Gibbons 2002) on each other: words and phrases are empty without meanings, but the pro-

cess of meaning construction necessitates a language to express thoughts. Hence, additional semiotic resources are required to structurally mediate both trajectories. For this challenge, the percent bar serves as a structural link that has already proven its relevance for conceptual developments (van den Heuvel-Panhuizen 2003). The percent bar can also offer linguistic support as it allows the use of deictic means for expressing ideas ('this', 'there') about meanings, and then offer a structural base for ordering different words and phrases in their relation to each other (middle column in Table 1). At a deeper level that students achieve later on in the course, the percent bar can serve as reference structure and thought model of problem situations. It can therefore be considered as a *structural scaffold* with an empirically reconstructable important function (Pöhler & Prediger 2015).

Table 1 Intended dual learning trajectory: intertwining conceptual and lexical learning trajectories with structural scaffolds (Pöhler & Prediger 2015; this article focuses on Level 1 to 3)

Levels	Conceptual learning trajectory: Mathematical conceptions	Structure-based scaffolding by percent bar (different functions)	Lexical learning trajectory through different vocabularies
Level 1: Informal thinking starting from students' resources	Constructing meaning for percents by representing and estimating rates (in context download bar)	Introduce percent bar as *model of* a familiar context (download bar)	Intuitive use of *students' resources in everyday register*, limited offer of new lexical means
Level 2: First informal strategies and basic meaning-related vocabulary	Developing informal strategies for determining rates, amounts and later bases (shift to shopping context)	Percent bar as *model of* situations, used to find informal strategies and to structure the relations of concepts and context elements	Establish *basic meaning-related vocabulary* in the academic school register for constructing meaning for rates, amounts, bases in shopping context
Level 3: Procedures for standard problem types	Calculating amounts, rates and later bases (in shopping context)	Percent bar as *model for* calculating and structuring the relations of meanings and formal elements	Introduce *formal vocabulary* in the technical register
Level 4: Extending the repertoire	Widening to other problem types: change and comparison (in shopping context)	Percent bar as *model for* constructing more complex relations	Enrich the *basic meaning-related vocabulary* to more complex problem types
Level 5: Identification of different problem types	Identifying problem types of (also non-)standard prob- lems (in diverse contexts)	Percent bar as structural base for identifying problem types	Explicit use and training of formal and basic meaning-related vocabulary
Level 6: Flexible use of concepts and strategies	Cracking more complex context problems flexibly (in non-familiar contexts)	Percent bar as structural base for identifying problem types	Introduce extended reading vocabulary

The intended dual learning trajectory is designed for a remedial percentage course for seventh graders with low achievement in mathematics and German (age 12-14 years). The course consists of three to five sessions, 60 to 90 minutes per session. The course consists of 20 sequential instructional tasks, and most of these tasks combine the lexical and the conceptual learning trajectories. Table 2 illustrates six tasks (on Levels 1 to 3, including transitional levels) which this article focuses on (notice that the columns in this table do not stand for the different trajectories).

In order to implement the hypothetical learning trajectories developed according to macro-scaffolding principles, three scaffolding means are activated: the percent bar which acts as a structural scaffold, the sequence of tasks, and the teachers' micro-scaffolding moves.

In order to implement the micro-scaffolding strategies and moves into the intervention, teachers are systematically trained in micro-scaffolding moves (cf. Table 3 in Section 5.1 for examples) to (I) constantly notice the students' thinking and language (diagnosis), (II) adapt their moves to this thinking (responsiveness), and (III) systematically fade out the interactional support (handover to independence).

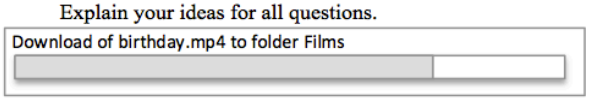
Table 2 Six of the twenty tasks in the dual learning trajectory (Pöhler & Prediger 2015)

Task 1. Download Bars (Level 1)

a) …

b) The friends download films and look at the download bars.

- What percent of the film has been already downloaded? (Tip: Portion the download bar suitably.)
- What percent of the film still has to be loaded?
- Can you express that also with a fraction? Explain your ideas for all questions.

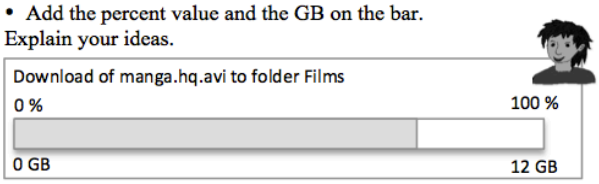


Task 3. Already downloaded (Level 1 → 2)

Kenan downloads a film of 12 GB.

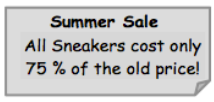
- How much GB has he already downloaded, approximately?
- Add the percent value and the GB on the bar.

Explain your ideas.



Task 5. Different offers for the favourite shoes (Level 2)

a) Maurice discovered an offer in the city. He draws the offer for his favourite shoes in a percent bar.



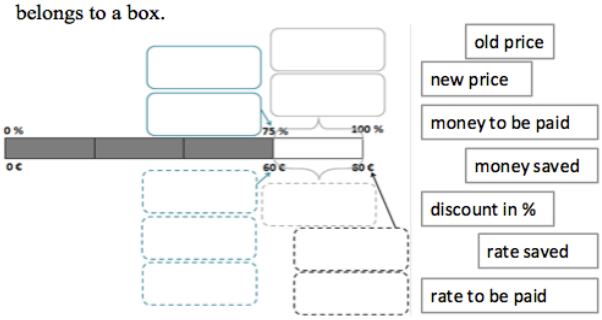
- What can you see in this bar?
- How has Maurice found the new price of 60 €?
- Compare to Kenan's bar in Task 3.

b) …

Task 7. Vocabulary for percent problems (Level 2)

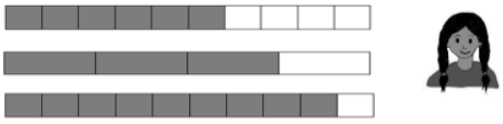
The words on the word cards can help you to describe offers and calculations like in Task 5.

- But which word belongs to what?
- Fill the boxes in the percent bar. Sometimes, more than one word belongs to a box.



Task 8. Different offers for the favourite shoes II (Level 2)

Taras favourite shoes used to cost 120 €. She receives three offers for discounts. How much does she has to pay?



- Complete all six values on the percent bars.
- Describe with the words from Task 7, what you can see on the percent bar.
- How much discount does she get in each offer?

Task 9. Filling gaps (Level 3)

a) Fill the gaps. You can use the percent bar. What do you discover? Explain your ideas.

(1) 5 % of 40 € are _____ €.
15 % of 40 € are _____ €.
25 % of 40 € are _____ €.

(2) 1 GB of 20 GB are _____ %.
2 GB of 20 GB are _____ %.
8 GB of 20 GB are _____ %.

(3) 30 % of 20 € are _____ €.
30 % of 30 € are _____ €.
30 % of 40 € are _____ €.

(4) 30 % of _____ € are 9 €.
30 % of _____ € are 18 €.
30 % of _____ € are 27 €.

b) Explain what is given and what is to find in the problems (1) – (4). Use the concepts base, amount, rate, and write them on the percent bar of Task 7.

3.4 Refined research questions

The description of the intervention with its dual learning trajectory allows to refine the research interest into two research questions that can be pursued in a local and a global perspective. The *local perspective* asks at a certain moment whether the move fits and contributes to the direction of change predefined in the intended learning trajectory, the *global perspective* asks for the interplay along the students' global learning pathway over several levels.

Q1. How can interactional micro-scaffolding moves support students' conceptual and lexical learning pathways towards percentages?
  Q1a. *locally*, i.e. in specific moments in the learning process?
  Q1b. *globally*, i.e. in adopting lexical offers into their individual lexicon?

Q2. How do the micro-scaffolding moves relate to the lexical and conceptual learning trajectories towards percentages?
  Q2a. From a local perspective, which learning trajectory does the micro-scaffolding moves refer to?
  Q2b. What *global* differences can be reconstructed between scaffolding moves on different levels of the learning trajectories?

4. Methodological framework of the empirical study

In their survey on a decade of research, van de Pol et al. (2010) find mostly descriptive research aiming at inventorying the kinds of scaffolding offered by tutors or teachers in laboratory studies or regular classrooms, and only a very small number of effectiveness studies. They conclude that more studies on effectiveness are required in future research (ibid., p. 283). Gibbons (2002) and Smit et al. (2013) suggest that a third kind of study is required before the effectiveness studies, namely design research in which an intervention is carefully designed and then subject to empirical investigations.

Since design research allows to understand the effects of scaffolding students' learning *processes* (not on achievements in tests). the study presented here is embedded in a larger design research project (see Gravemeijer & Cobb 2006 for the methodology). In four design experiment cycles, the dual learning trajectory towards percentages and its realization in several sessions was developed and then investigated with respect to different research questions (cf. Pöhler & Prediger 2015). This paper reports on a further empirical investigation of the interplay between micro- and macro-scaffolding, focused only on the fourth design experiment cycle and the Levels 1 to 3, for which the most intense preparation of the tutors took place.

4.1 Design experiments as method for data collection

Design experiments are considered to be the methodological core of design research studies as they allow in-depth investigations of teaching and learning processes in both laboratory and classroom settings (Gravemeijer & Cobb 2006). As the empirical study reported here investigates the relations between micro- and macro-scaffolding., the interaction conditions in this empirical study are optimized by design experiments in laboratory settings, where each participating teacher interacts with one or two learners at a time (Beren and Manik work together in a group, Melina and Kevin in a group, and Sebastian works alone). Unlike most interview studies that focus on short excerpts, the specificity of the data in the present study is the length of the investigated learning processes: Three design experiment series with three sessions each are conducted and videotaped, resulting in 590 minutes of video material altogether.

The teachers who participated in the intervention are experienced tutors with recent university degrees. They were intensively prepared for micro-scaffolding along the intended learning trajectories with a video-based training program. The participating students (n=5) are selected based on their difficulties with percentages and their limited second language proficiency in German.

4.2 Qualitative methods for data analysis

So far, most empirical research on the effects of micro-scaffolding has taken one of two approaches (van de Pol et al. 2010): Effectiveness studies control the quality of scaffolding strategies, but consider their effects only by comparing pre- and post-tests like in a black box. Existing qualitative studies mainly consider phenomena on a short time scale, showing how a certain move can bring the students forward in a specific moment in their learning process. The analysis of the present study combines this local perspective with a global perspective, taking into consideration students' learning pathways along three levels of a hypothetical learning trajectory.

The qualitative analysis of the 590 minutes video data began by categorizing the teachers' 460 *enacted scaffolding moves*. Each move (unit of analysis, usually encompassing one or two turns in the transcript) was categorized by two researchers with respect to seven types of micro-scaffolding moves (specified by merging distinctions of Smit et al. 2013, p. 824; Wessel 2015, p. 58f., cf. Table 3). The inter-rater reliability was measured using Cohen's Kappa ($\kappa = 0.89$). Additionally, the *students' lexical pathways* were reconstructed by inventorying all lexical means (words and phrases on relevant relations and concepts) used on the different levels of the dual trajectory (cf. Pöhler & Prediger 2015).

- *To answer the local research question Q1a* (how scaffolding moves locally support students' progress), the *students' conceptual pathways* were reconstructed in a sequential analysis with systematic extensive interpretation (cf. Prediger & Wessel 2013 for the methods), assigning the conceptual levels reached by the students to each transcript passage. Based on this analysis, the identified scaffolding moves could be related to the conceptual and lexical pathways in the transcripts of selected moments. Additionally, analytic tools for the trace analysis were developed.

- *To answer the global research question Q1b* (how scaffolding moves globally support students lexical progress), a new procedure was developed called *trace analysis*. It traces the used lexical means back to oral and written sources offered to students, or identifies them as introduced by the students themselves. This allows to compare the relevance of tasks and oral moves for scaffolding. Each of the lexical means students used is categorized as self- or teacher initiated. Section 5.1 illustrates the categories based on concrete data.
- *To answer the local research question Q2a* (reference of micro-scaffolding moves to learning trajectories), the transcripts of selected moments in the video were analyzed with respect to the different ways micro-scaffolding moves were related to the macro-scaffolding conceptual and lexical learning trajectories. One result of this second categorization process are four reference categories:
  - *conceptual reference:* direct the students' conceptual pathway along the conceptual trajectory,
  - *lexical reference:* direct the students' lexical pathway along the lexical trajectory,
  - *structural reference:* provide students with hints to use the percent bar as a structural base, and
  - *no reference needed:* no connection to the dual hypothetical learning trajectory.
- *To answer the global research question Q2b* (on different references of scaffolding moves between different levels), all types of teachers' micro-scaffolding moves that support the progress in the basic analysis were categorized according to the categorization developed in Q2a (with an inter-rater reliability achieved by a discussion between the two researchers). The analysis of frequencies with respect to the types, reference categories, and conceptual levels 1-3 allows a quantified global overview on the differences between the levels.

Whereas the research questions in local perspectives invites to consider each passage of transcripts on their own rights, adopting global perspectives on the data encompassed allows to consider the trajectories and pathways as a whole in their connections and differences. This combination of analytic methods seems to be crucial for taking into consideration the macro-scaffolding.

5. Empirical Analysis

As mentioned in Section 3.5, the formative assessment of students' pathways show that all students acquired the intended conceptual understanding and some lexical means for communicating purposes (Pöhler & Prediger 2015). From this perspective, the interplay of micro- and macro-scaffolding is investigated in this study.

5.1 Role of micro-scaffolding moves for students' lexical pathways – Local perspectives

The implementation quality of micro-scaffolding with respect to the micro-scaffolding characteristics (I) to (III) is illustrated by categorizing all teachers' scaffolding moves into seven types of moves. Table 3 shows the types of moves with examples from the design experiments and the frequencies of occurrences in the video data of 590 minutes of intervention.

Table 3 Micro-scaffolding moves with realized examples and frequency of occurrence in the intervention

Type of micro-scaffolding move	Example from the analyzed processes	Frequency of occurrence
(1) assign competence to the students	"You are right in saying 20 : 5 is 4."	333
(2) make explicit the communicative expectations	"Describe it as if I had never seen this task before."	5
(3) refer to the structural scaffold (percent bar)	"I would first fill [in the percent bar], that you know that 70 % is 28 €. That is what you know."	11
(4) ask for clarification or improvement in spoken language	"What does that mean? New price?"	37
(5) use gestures or drawings to support verbal reasoning	"How could you [use] the bar? We had divided it nicely for other tasks […] Could you do that here, too, perhaps?"	20
(6) repeat correct utterances or reformulate partly correct ones	„Exactly, it increases, too." [After "It gets more."]	31
(7) connect and summarize on a meta cognitive and meta linguistic level	"Exactly, now you have said, that the concepts base, amount and rate are better describing more general situations."	23

For counting the frequencies, all 460 moves have been assigned to only one type even if these types overlap sometimes. The third column shows that Type 1 (assign competence to students) contains the most moves by far. Its 333 occurrences reflect low achievers' specific needs for positive feedback. However, they do not count as scaffolding moves in a narrow sense as they rarely adhere to key characteristics (II) and (III). Among the other types, the most frequent moves are Types 4, 6, and 7.

This quantitative overview invites to investigate research question Q1a, to explain how the scaffolding moves support the students' use of lexical means for percent concepts and their relations with the lexical learning trajectory.

The analysis starts in a local perspective by contrasting two short episodes (in which the **micro-scaffolding moves** and relevant lexical means used by students are highlighted).

Episode 1. Kevin's use of lexical means after teacher's initiation

Kevin works on a task (cf. Fig. 4) in the new tombola context. He first tries to express the relations with the lexical means from the shopping context ('old price', 'new price', 'reduced by'), but discovers that they are not suitable for the new context.

1664 K Huh, but how is it possible? It isn't Euro and so on.
…
1669 T **So it doesn't work well with new and old price**.
1670 K Because. There is none.
1671 T Mm. **What could you say instead of new and old price?**
1672 K Yes. The base.
1673 T Okay, then we make it like this.
1674 K Well, the base is 200 lots. And eh I have the amount of 90, and the rate for 45 %.

Task 16. In a tombola 45 % of all lots shall win. These are 90 winning lots. How many lots were sold?

Fig. 4 Task 16 treated in Episode 1

Whereas Kevin uses 'old price' in a *self-initiated way*, he is more reluctant with the use of the formal vocabulary 'base', which was previously offered to him in the *written* material. It is typical for the *teacher* to *initiate* students' use of formal vocabulary by explicit questions (in #1671, Type 4 micro-scaffolding move), after making the meta-linguistic point that the meaning-related vocabulary from the shopping context is not suitable (Kevin in #1664, teacher in #1669, Type 7 micro-scaffolding move).

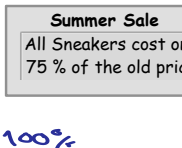
Episode 2. Beren and Manik's self-initiated use of lexical means

While working on Task 5 (cf. Fig. 5), the girls Beren and Manik experience difficulties in understanding the illustrated situation mathematically, but are able to use lexical means without being explicitly prompted by the teacher:

501 T **Exactly, what can you see in the bar?** […]
502 B So anyway, I don't understand it. If there is anything, for example 60 €, 80 € or so on.
503 M Now, I have, I believe, an idea, that it will cost 20 then and this 40.
504 T Mm.
505 M And this 60 and this 80. *[hints to the bar]*
506 T Okay. First we make your question. **What don't you understand?** [*to Beren*]
507 B So, if there is 80 € for example and then 75, thus, there is only 75 percent. So this is cheaper then? Because I don't understand how, how you find this money, so how many Euros.
508 T The 60 €? **You don't know how you find the 60 €?**
509 B No.
510 T Okay.
511 B I mean, for example, mh, there is, mh, the shoes cost 60 € and 75 €, mh, thus are cheaper.
512 T 50, thus 25 percent is cheaper than 100 percent, now?
513 B No, I mean, eh, it is 60 €.
514 T Yes.
515 B And thus the shoes cost 60 € now.
516 T Yes.
517 B And 75 percent are – it became cheaper.
518 T Mh.
519 B And then I don't understand how you the money, thus how you find how many €.

Task 5. Different offers for the favourite shoes (Level 2)

a) Maurice discovered an offer in the city. He draws the offer for his favourite shoes in a percent bar.



- What can you see in this bar?
- How has Maurice found the new price of 60 €?
- Compare to Kenan's bar in Task 3.

Fig. 5 Task 5 treated in Episode 2

The teacher initiates that the students elaborate their ideas (by using Type 3 scaffolding moves in #501 and Type 4 in #506 and #508) but does scaffold the use of specific terms. In addition to the adaption of lexical means offered in the written task or orally by teacher ('be cheaper' in #507, #511 and 'become cheaper' in #517), the girls also use self-introduced words ('cost … €', in #503, #511 and 'cost … € now' in #515). Furthermore, their struggle with expressions for 'amount' is striking.

Contrasting these two and many other episodes allow to specify five different categories of (written or oral) scaffolding offers being adopted by students:

- two local categories, distinguishing whether the use of lexical means is
  - (S) self-initiated by the student in this moment (usually, the task sets a certain necessity but does not ask for specific words or phrases) (see #507 for example), or
  - (T) teacher-initiated (see #1671 for example)
- three global categories for sources of potential lexical means (which require the lexical inventorization of the complete process):
  - (w) lexical means offered in written materials (see #1671 for example), and / or
  - (o) lexical means offered orally by the teacher (see Beren in #507 for example), or
  - (*italics*) students inventing or modifying their lexical means themselves (for example, see Beren in #503: with 'cost … €')

5.2 Role of micro-scaffolding moves for students' lexical pathways – Global perspective by trace analysis

The trace analysis with these five categories is conducted to reconstruct the relationship between students' lexical pathways and the lexical means offered by various scaffolding means (written materials, or teacher's oral scaffolding moves). Table 4 shows one typical result, the trace analysis for the case of Beren and Manik:

- The table organizes the Levels 1 to 3 of students' conceptual pathway (cf. Table 1) into rows, with sub-rows for expressions relating to comparing, base, amount, and rate.
- The left hand column inventories all lexical means offered: in task formulations (written offers, w) and teacher's speech (oral offers, o); new words or phrases arising for the first time are marked in *italics*.
- The right hand column inventories the lexical means used by Beren and Manik during the analyzed design experiment sessions. The words without italics are adopted from the written or oral offers; the words in italics are invented or modified by the students.
- (L) signifies that the teacher initiated the use of the new word, (S) refers to the students' initiative. The number signifies the frequency of later occurrences. As the analysis stopped on Level 3, the frequencies for the third level are lower.

Table 4 shows the rich repertoire of lexical means applied by Beren and Manik during their whole lexical pathway.

The lexical means students used are level specific: At *Level 1*, students mainly use lexical means to refer to the graphical aspects of the bar (for example the use of the adjectives 'long', 'dark' and 'light') and sometimes to refer to the download context ('is already / fully loaded' and 'still must be loaded'). The graphical references disappear during the *shift to Level 2* and slightly reappear in the shopping context (bar and grey bar). Additionally, the shift to Level 2 can be characterized by an increase of lexical means for relations ('… % are … GB' or '… GB at … %') or comparisons ('other GB' or 'be larger than') as the tasks now focus on the relations of the double scale, for which the students also find own words ('at GB / at percent (at the bar)').

At *Level 2*, the rate of self-invented expressions decreases significantly. This is in line with the hypothetical learning trajectory which begins with students' resources and then deliberately offers students basic meaning-related vocabulary (students either adopt this vocabulary or change it slightly, e.g. 'be cheaper' is offered, but the students say 'be made down').

Table 4 Lexical means used by Beren and Manik in the different levels in relation to the offers (new words or phrases in *italics*)

Level	**Lexical means offered in written scaffolding means (w) or oral scaffolding means (o), i.e. the teacher's speech** (*italics*: new words or phrases)	**Lexical means used by students, initiated by the students (S) or the teacher (T)** (*italics*: self-invented / modified words or phrases)
Level 1	• *download bar (w / o)* • *bar (o)* • *long bar (o)* • *dark bar (o)* • *... % is already loaded (o)* • *... % of the film already has been loaded (w)* • *light stripe (o)* • *... % still must be loaded (w / o)*	• bar (S) • long bar (S) • dark bar (S) • … % is already loaded (T) • *... % is fully loaded* (S) • *be ... %* (S) **1** • *the* light stripe (T) • … % still must be loaded (T) **7**
Shift from Level 1 to Level 2	• *at the top and at the bottom of the bar* (o) • *more / less be loaded* (o) • *be larger than / smaller than / just as large as* (o) • download bar (w / o) • bar (w / o) • *a film of ... GB* (w) • *be ... GB large* (w / o) • *be ... %* (o) • *has been loaded up to ... % / GB* (o) • *... GB* (already) has been / be loaded (o) • *have loaded ... GB of ... GB* (w) • *... % are ... GB / ... GB are ... %* (o) • *... GB / % still missing* (o) • still must be loaded (o)	• *at GB / at percent* **3** *(at the bar)* (S) • *be more* / larger **2** *than* (S) • bar **2** • *other GB (for another movie size)* (S) • be … % **4** (S) • *already have ... % / GB* (S / T) **6** • *has been charged up to ... %* (S) • … % are … GB **18** / … GB are … % **4** (S) • *... GB at ... %* (S) • *still need / load ... GB* (S) • … GB / % still missing (S) • … GB still must be loaded (T) **4**
Level 2	• *offer* (w / o) • *summer sale* (w / o) • *be cheaper / be the cheapest* (o) • *... have changed / be different* (o) • download bar (w) • bar (w / o), *percent bar* (w) • *complete bar* (o) • *old price (is)* (w / o) • *cost ... € before* (w) • *have cost ... €* (w) • *be ... € expensive before* (w / o) • *grey* / dark bar (o), *highlighted* bar (o) • *up to wher the grey is going* (o) • be loaded (o) • be … % / € (o) • *money to be paid* (w) • *rate to be paid* (w) • *new price (is)* (w / o) • *is ... € expensive now* (w / o) • *only cost ... % / €* (o) • *price be ... € high* (o) • *have to pay ... % / €* (w / o) • *only ... % of ... €* (w) • *(still) cost ... % of the old price* (w / o) • *... % are ... €* (o) • *white bar* (o) • light *part* / bar (o) • still must be loaded (o) • *save / saved ... € / ... %* (o) • *(become) ... % / € cheaper* (o) • *discount* (w / o) • *give* (w / o) / *have* (o) *discount of ... %* • *discount be ... % high* (w) • *money saved* (w / o) • *rate saved* (w) • *be reduced* (w / o)	• be cheaper (S) **1** • *be more expensive* **3** / *smaller* **2** / *equal* **1** (S) • *bar* (S) • *at the end of the bar* (S) **3** • old price (is) (T / S) **4** • cost… € before (S) **3** • *how much it has cost before* (S) • grey bar (T) • be loaded … GB (T) • money to be paid (T) **2** • money *still must* be paid (T / S) • *money you give away* (S) • rate to be paid (T) • new price is (T/ S) **4** • *cost money* (S / T) • *cost ... € (now / then)* (S) **3** • be … € **3** / % **5** (S) • *would cost ... €* (S) • *still remain* (S) **2** • … % are *like / is ... €* (S) **22** • *... % cost ... €* (S) • saved / *could save* (S) **3** • become … % / € cheaper (S) • *become (... %)lower price* (S) • *be reduced (to)* (S) • discount (T / S) **1** • give discount of … % (T) • money saved (T) **1** • rate saved (T) • *save ... % (disount / money)* (S) **4** • *be made cheaper* (S) • *be made down* (S)
Level 3	• base (w) • amount (T) • rate (w)	• base (T) **2** • amount (T) • rate (T) **3**

Comparing the *used* terms with the *offered* terms shows that students adopt teacher's oral offers at *Level 1* besides their self-introduced terms much more than originally predicted. As expected, the rate of adopted words increases at *Level 2*. However, it is interesting to see that the adoption of lexical means offered at Level 2 in written form rarely takes place automatically. Instead, it often requires the teacher's explicit initiative (T in the right hand column). At *Level 3,* the adoption of *all* technical terms is teacher-initiated.

These tendencies found in the trace analysis of Beren and Manik's learning process could be reconstructed in a similar manner for the other analyzed cases and therefore provide answers to research question Q1b:

- While descending deeper into the levels of the dual trajectory, the character of the expressions changes from single words to complex phrases expressing relations and comparisons,
- the source of the expressions changes from mainly self-introduced to mainly adopted from offers,
- the first use of lexical means on deeper levels is initiated more by the teacher's micro-scaffolding moves than the previous levels.

5.3 Role of lexical and conceptual learning trajectories for micro-scaffolding moves – Local perspective

The relevance of scaffolding moves for students' lexical learning pathway has been shown in Section 5.2 by the large number of lexical means adopted by students from oral offers. This section presents results to research question Q2a, which asks vice versa, for the role of referring to the trajectories for the moves and their effects. Again, the analysis begins by contrasting two episodes from a local perspective.

Episode 3. Sebastian and transfer of meaning-related terms to a new context

Sebastian works on Task 7 on Level 2 (full text in Table 2, main structure in Figure 6), in which meaning-related vocabulary from the shopping context must be placed on the percent bar.

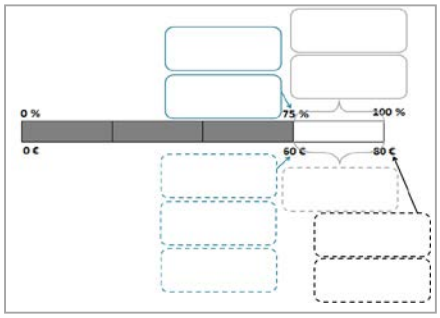


Fig. 6 Main structure of Task 7 treated in Episode 3

702	S	[*Sebastian takes the card 'new price' and places it to 60 €]*
703	T	Mh, **why there**?
704	S	Because it is the new price then. Thus, before it was 80 € and they were reduced.
705	T	**So the new price is the 60 €?**
…		
708	S	The old price. Yes. This is 80 €.
709	T	Okay.
710	S	That is – mmh – the money saved, which is between it.
711	T	**What was the amount which you saved there?**
712	S	Mh 20 €.
713	T	Okay.
714	S	Money to be paid.
715	T	**Like the new price – 60 €. Right.**
716	S	But actually it must says 20 % discount.
717	T	**20 €. Right?**
718	S	Oh 25 %. That is this [*hints to the card 'discount (%)'*].
719	T	Right. **Because you have this arrow here, it puts the small piece together. And how big is this piece? The part?**
720	S	¼
721	T	Right. ¼ or 25 %. Right?
722	S	What is the difference between the rate saved and the money?
723	T	**Well, part** [she means amount or piece] **means usually these – thus piece – pieces for example. Or, percentages were often described as parts. Right. Because you have this separation the money below and above the part. The part you can take as a general term because it works in every situation.** […] I**n the context of the downloadbars of films we could never say money because it is about gigabyte. But you can always say amount.**

An analysis of the teacher's micro-scaffolding moves shows that she refers her actions to the conceptual and lexical hypothetical learning trajectory, in a local and a global way. She supports the student's *local* meaning construction by reformulating his phrase 'Money to be paid' (#714) by a term on a card 'Like the new price – 60 €. Right.' (#715). This is a typical move of Type 6 move (see Table 3) in which she pushes him forward locally on the conceptual and lexical pathway.

The teacher also works on the *global lexical pathway*. In her explanation in #723 (Type 7 micro-scaffolding move), she approaches the formal vocabulary on Level 3 and offers an explanation for their

necessity (being independent of situations). In the same utterance, she connects this outlook on Level 3 with the previous Level 1 experiences on download bars. Having the complete learning trajectory in mind allows the teacher to diagnose the student's learning progress locally (characteristic I), to be responsive (characteristic II), and to hand over independence in the long run (characteristic III).

However, her scaffolding goes beyond that: She prepares the student for the next level of development by giving him the preliminary reasons for a formal, context-independent language and connecting this language to Level 1. Generally, this explicit connection of the levels shows her strong reference to the long-term trajectory. Hence future research should consider this relation more systematically. The success of this scaffolding can be measured by revealing Sebastian's ability to deal with the vocabularies and their meaning in the following excerpt.

Episode 4. Sebastian and the confusion of estimating and calculating

Sebastian works on Task 6a (cf. Fig. 7) which requires him to calculate the new price of a pair of jeans, given the original price and the discount in percent. This Level 2 task specifically aims at developing informal strategies for calculating amounts.

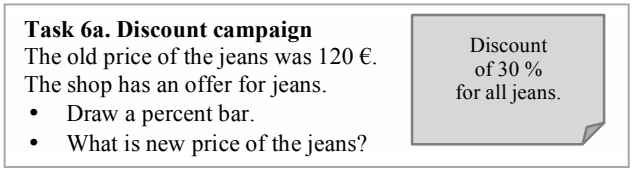


Fig. 7 Task 6a treated in Episode 4

601 T Okay. **What does it mean, there is a discount of 30 %?**
602 S Mh yes. Thus 30 % will be subtracted.
603 T **This means, which percentage do we have to pay?**
604 S 70 %
605 T Okay. **Exactly. Then you can mark it in the bar.**
606 S I shall estimate here, right?
607 T **Yes, you can estimate this.**
608 S Shall I estimate this again?
609 T Yes. Think about that. […]
610 T You have, you have estimated this. You marked 70 % and 80 €. **How did you find it?**
611 S So. I have 70 % here. Well, I first I took the half again and mh the half of it – 25 %. So these are 75 % of […*incomprehensible word*] plus 25. Then, I estimate a bit, what could be 5 % here.
612 T Okay.
613 S So 80 % is 30 %, mh % are 1/3. Yes. 1/3? [*Break*|]
614 S Yes. Approximately. Yes I simple have. Yes, and then, because 1/3 is 25, thus 80 €.
615 T Exactly. Well, but actually 70 % are 84 €. Right? But you estimated well. Because, you have to estimate. Mh. It is like that that you could think, these 120 € are 100 %. Thus you could think how many are 10 %. 10 % are 12 €. 12 times 7 and then you find your result. Then you find the 84 €.

Considering the episode in a local perspective shows that micro-scaffolding moves support the student's learning progress, e.g. the teacher's question in #603. Sebastian produces an estimation that is completely adequate on Level 1 and is supported to give an elaborate explanation.

However, in a global perspective, his solution is not adequate since on Level 2, he is asked to determine a calculation strategy rather than an estimation. Although he offers fruitful starting points for a calculation strategy in #611, the teacher's support stays on Level 1. Then she does the calculation by herself in #615. Hence, this episode gives an example of micro-scaffolding that is responsive and is in line with the lexical learning trajectory, but addresses an inadequate level on the conceptual learning trajectory by which learning opportunities are wasted (for which characteristic IV is required).

5.4 Role of lexical and conceptual learning trajectories for micro-scaffolding moves – Global perspective

Both episodes show that characteristic (IV) (reference to the learning trajectories) should be considered independently from characteristic (I) to (III). This motivates the researchers to adopt a global perspective and analyze to what extent all 127 micro-scaffolding moves of Types 2-7 (without those of Type 1, assigning competence to students, cf. Table 3) refer to the conceptual and lexical learning trajectory. Additionally, the coding of the conceptual levels allows the investigation of research question Q2b with regards to the differences between the scaffolding moves on different levels of the trajectories.

Table 5 gives examples of each level for the three ways of referencing to the trajectories. The column in the middle shows to which type the moves belong. Besides references to the *lexical* and the *conceptual* learning trajectories, references to the *structural* scaffold turn out to be of major importance, i.e. to the percent bar by which lexical and conceptual learning trajectories are tied together (cf. Table 1). Table 5 also shows moves with double or even triple references. In most times, the structural references play a role in these combinations.

Table 5 Examples for micro-scaffolding moves in different reference categories with types and levels

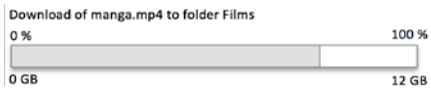
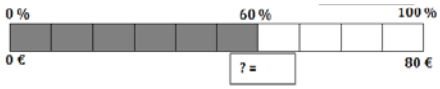
Ways of reference with examples for each level in the intended learning trajectory	Type	Level
Conceptual reference – a shift along the conceptual trajectory		
 "Did you say, well, it is eighty percent here, these are ten. How did you find the 10 gigabyte then?"	(4)	1
 "This with the 50 % didn't help you for the 60 %, right? And the 25 % neither. Though, you went lower at 10 % now and so it works, right?"	(7)	2
5 % of 40 € are _____ €. 15 % of 40 € are _____ €. 25 % of 40 € are _____ €. "For 15 % you had 6 Euro."	(6)	3
Lexical reference – a shift along the lexical trajectory		
"Could you say it in other ways than 50 %?"	(4)	1
"You can use some words for the download bar and some not. Which words could you use for both things, to describe them"	(7)	2
"Exactly, now you have said, that the concepts base, amount and rate are better describing more general situations."	(7)	3
Structural reference – a hint to use the percent bar as a structural base		
"What happen if you compare it, up there, with the bar? Could it help you?"	(5)	1
"Are all equally big, right? All fields, yes."	(5)	2
"Before, label [the bar] properly. Beren, label everything correctly before [calculating]."	(3)	3
Conceptual and lexical reference		
"Right, as a result of the change of the base, the rate has changed, too."	(7)	3
Conceptual and structural reference		
"How could he have calculated, if you look at the bar?"	(5)	2
Lexical and structural reference		
"Simply describe [the percent bar] with the words we had lying here earlier."	(5)	3
Conceptual, lexical and structural reference		
"Once again back to the download bar. What shows the grey here? And the white? And how would it be here? [in the shopping context]"	(3)	2

Figure 8 shows the occurrences of references on Levels 1 to 3. The right hand column summarizes the moves and shows that 41 % (47 of 114) of the moves have no reference to the learning trajectories, and most of them belong to the content-independent Type 2 move (make explicit the communicative expectations). 59 % of the moves refer to at least one of the trajectories or structurally based scaffolds. This shows the strong interplay between micro- and macro-scaffolding.

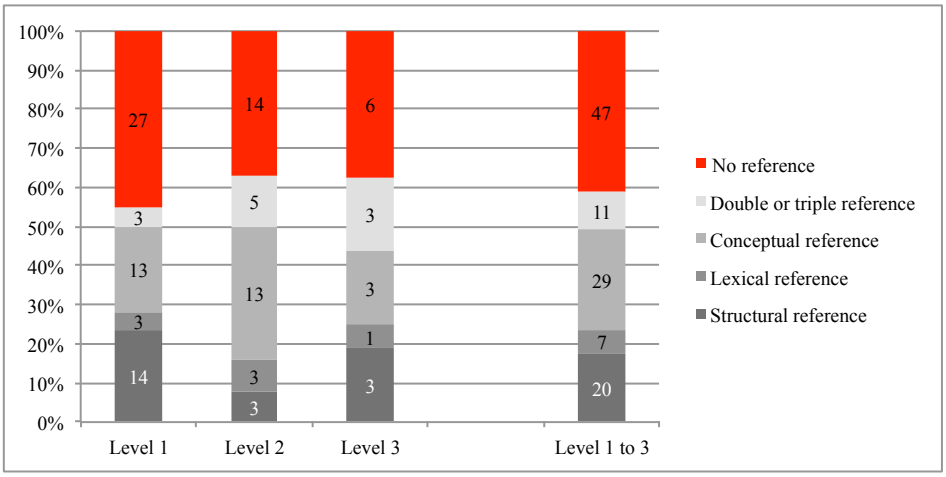


Fig. 8 Distribution of references over the three levels of the conceptual learning trajectory

The percent bar is often emphasized as a structural scaffold (25 %, i.e. 29 moves: 20 are hints to use the bar as a structural scaffold and 9 hints to use the bar along the conceptual or lexical learning trajectory). Shifts along the conceptual learning trajectory are most frequent, while the shifts along the lexical trajectory are often combined with structural or conceptual references. In only 7 cases (not shown in Fig. 8) the moves also make the levels explicit.

The ways of referencing to the learning trajectories differ on the three levels (cf. same colors in the three left hand columns of Fig. 8): The rate of moves which point to the structural scaffold decreases from Level 1 (23 %) to Level 2 (8 %). Level 2 requires the most shifts along the conceptual trajectory (13, 34 %). Furthermore, the double and triple references appear more frequently on the higher levels. Hence, once students established the percent bar as a structural scaffold on Level 1, it is mainly used to support the lexical and the conceptual learning trajectory in the later levels. Apart from that, the levels do not strongly differ with respect to the references.

6. Conclusion and Outlook

Although some authors criticize the extension of micro-scaffolding to macro-scaffolding as an unnecessary generalization (summarized by Smit et al. 2013, p. 818), the presented study strengthens the arguments pushed forward by Smit et al. (2013) and Hammond and Gibbons (2005) that micro-scaffolding for conceptual and language learning should always be considered in its relation to the macro-scaffolding of the intervention. This macro-scaffolding can be operationalized by specifying hypothetical learning trajectories (Smit 2013; Pöhler & Prediger 2015). Whereas earlier papers mainly emphasize the relevance of the *design layer*, this study stresses the necessity to extend the *research tools and perspectives* in order to account for the interplay between micro- and macro-scaffolding, in a local and a global perspective.

In order to gather preliminary answers to the overall research interest "How does micro-scaffolding depend on aligning students' learning pathways to these intended learning trajectories?", the study investigates how interactional micro-scaffolding moves support students' conceptual and lexical learning pathways towards percentages (Q1) and how they refer to the lexical and conceptual learning trajectories (Q2) in a local and in a global perspective.

With respect to the research question Q1a, we find that from a local perspective, teachers' moves are necessary for pushing students forward, especially in deeper levels of the learning trajectory where students rarely adopt vocabulary from the written material. From a global perspective (Q1b), we introduced the method of analysis called *trace analysis* to reconstruct how students' use of lexical means depends on written and especially oral offers. Furthermore, the trace analysis shows that the character of the expressions used by the students change from single words to complex phrases and their source change from mainly self-introduced to mainly adopted from offers while descending deeper in the levels.

The investigation of question *Q2* shows that in the intervention, 59 % of the scaffolding moves took reference to the learning trajectories (especially to the conceptual learning trajectory and to the percent bar as a structural scaffold) in order to locally align the students' learning pathways. However, we find that scaffolding moves can satisfy the key characteristics of diagnosis, responsiveness and handover to independence locally on a certain level of the learning trajectory without considering the global trajectories. That is why besides the well-established design layer, a fourth key characteristic of reference to the learning trajectories as a macro-orientation is required for research and for teachers. This should have consequences for professional development and for future research.

With respect to the methodological limitations of the current study (the small sample size of five students, the restriction to laboratory settings, and the focus on one single mathematical topic: percentages) the results should be read with some methodological caution. However, the preliminary results are promising and worth being transferred to other conditions in future research.

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