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The dynamics of scaffolding

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Abstract

In this article we have reinterpreted a relatively standard definition of scaffolding in the context of dynamic systems theory. Our main point is that scaffolding cannot be understood outside the context of a dynamic approach of learning and (formal or informal) teaching. We provide a dynamic systems model of learning and teaching in which the notion of scaffolding plays a central role. The model is illustrated with a study of the math learning of five children in a school for special education. The model predicts various non-linear properties of learning and teaching phenomena, which need to be tested in further empirical research. In order to explain scaffolding and learning processes observed in real contexts, the basic dynamic model must be embedded in a broader model, that of embodied and socially situated dynamics of concern-governed action.

1. Dynamic principles of scaffolding processes

Tuesday morning at nine. Nine children, aged between 8 and 10 years, from a school for special education in a small city in the North of the Netherlands, have their daily math class. About half of the pupils are scribbling in their exercise books, making their math assignments from the workbook, some still in the beginning of the book, others already at a much more advanced level. Of the other pupils, one is just staring in the void, one is saying something to his neighbor and another is sharpening a pencil. One, A, is sitting next to the teacher ("Juf"[1]). Juf is shepherding A through an exercise, meticulously demonstrating all the steps A must take.

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[1]is the Dutch word for female teacher at the elementary level; it is pronounced like the English "cough", but with an initial J as pronounced by the Swedish chef from the Muppet Show.

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All the pupils have a two-colored plastic brick on their desk. The pupils who are diligently writing in their exercise books have the red side on top, but some of the pupils have the green color on top. That's how they tell Juf that they need help. As A is going back to his own desk, books under his arm, Juf calls B to come to the front. B explains his problem, Juf looks at him and tells him which general rule he should follow in order to solve the new type of sum he is just begun to make. B goes back to his desk and continuous his work. Meanwhile, A after having stared at his exercise book for about 10 s, has turned the green side of the brick up again and waits.

The current scene is fairly typical of how the math classes proceed in a school for special education that the current authors have just begun to study. The aim of this study is to follow five children intensively over a period of 2 years and to try to discover the socially situated dynamics of learning in this setting, where learning is endangered due to the children's behavioral and clinical problems. Math lessons are videotaped twice a week, over a period of 2 years. In addition, information is collected from the pupil's workbooks (assignments they have made), with and without help of the teacher.

As to the current article, we shall use this example to present a theoretical speculation about the dynamics of scaffolding. The aim is to present a theoretical contribution by showing how the notion of scaffolding can be transformed into a dynamic systems model of socially situated learning and to show how such a dynamic model can contribute to specific explanations and predictions of learning-and-teaching processes.

1.1. Dynamic systems and scaffolding: definitions

A dynamic system is simply a means of describing how one "state" (property, level, …) changes into another "state" over the course of time (Weisstein, 1999). Hence, a model that describes how the scaffolding given to A on Tuesday morning changes into the scaffolding given to A on Wednesday morning, or Tuesday next week or next month, is a dynamic system of scaffolding (see van Geert & Steenbeek, 2005, for a discussion of dynamic systems in developmental psychology). The aim of such a model is to contribute to the understanding and prediction of long-term processes of learning and teaching.

A dynamic systems model aims at explaining the change by providing a mathematical representation of the process. Dynamic models, for instance of the scaffold and learning process, can range from almost minimalistic models specifying the change of a single—or two coupled—variable(s) over time (for instance scaffolding and learning) to elaborate models of embodied action in a specific spatio–temporal-material context. The first type of models have been introduced by Van Geert (van Geert, 1991, 1994a, b, 1998a, b, 2003) The second type of model is typical of the work of Thelen, Smith, Spencer and others (Smith & Thelen, 1993; Spencer & Schöner, 2003; Thelen & Smith, 1994). In the present paper, we will focus on the first type of model and provide some suggestions of how its validity can be enhanced by embedding it in a dynamic model of embodied, socially situated action (see for instance Steenbeek, 2006).

Granott and co-authors (Granott, Fischer, & Parziale, 2002) define scaffolding by comparing it with the building of a roman arch. Applied to learning, scaffolding is the use of some "external" support that makes a particular learning process possible and that can be discarded after the learning has taken place. "External" in this respect means "external to the learning process at hand". Granott et al. (2002) distinguish self-scaffolding from other-scaffolding. In the context of the math class from the introductory section, an example of other-scaffolding is the teacher's sequence of concrete instructions to pupil A. An example of self-scaffolding is A's writing down the sums from the printed workbook. This form of self-scaffolding is closely related to what Granott et al. (2002) call bridging. In addition, Valsiner (1989), among others has argued that a major part of the scaffolding is embodied in a material form. For instance, the pupils' math workbooks provide an explicit material scaffold, e.g. by sequencing the math problems in a way that enhances the learning in the best possible way. In the present article, however, we will focus on other-scaffolding incorporated in the help given by the teacher.

Scaffolding is an intrinsically dynamic notion. It describes how a particular level of knowledge or skill in a student changes as a result of the scaffolding process. That is, it describes learning as a result of the help given at a level close to the student's current level of unaided or unassisted performance (see definitions given in the next section). Empirical studies have shown (1) that the scaffold function or process exists, (2) that it is effective in that it advances learning and (3) that it has different forms, i.e. that it differs among individuals and contexts (see, for example, an overview in the context of learning disabilities, Stone, 1998).

1.2. Towards a conceptual model of scaffolding dynamics

In line with dynamic systems thinking, the current study—and the introductory example—suggest a distinction between the time-scale of the actual scaffolding process and the time scale of learning over a longer time. A major question in dynamic systems thinking regards the relation between the time scale of action—the actual giving of help by the teacher—and the effects of such scaffolding on learning in the long run, for instance the pupils' progress in the math curriculum over the course of months. It is a major question also because it relates to the fundamental practical problem of teaching: what to do on the time scale of real action (in this particular case, which help or scaffolding to give) in order to support a long-term process (learning in the pupil) that cannot be manipulated directly. How is this relation between those time scales explained in the current approaches to scaffolding?

Take for instance the following definitions: scaffolding means

> providing support at the right level of the current skill while a student is carrying out the task and then gradually fading out of assistance (Järvelä, 1995)
> or
> providing assistance to students on an as-needed basis with fading out of assistance as the competence increases. (Pressley, Hogan, Wharton-McDonald, & Mistretta, 1996).

Thus, the definitions imply first, that there is some identifiable level of a student's skill, knowledge, etc., and, second, that there exists a support in the form of help, assistance, instruction and so forth, with a level specifiable on the same scale or dimension as the student's skill level and third, that this level is close to the student's level. The fourth implication is that giving this support results in the increase of the student's level (his competence) and, the fifth implication is that because of this increase the support can gradually disappear. The sixth, and final implication is somewhat more complicated and indirect. The support must be "at the right level of the current skill" of a student (see the first definition). Hence, if the level of the current skill increases as a consequence of the support given, the future level of support, needed to solve the new problems the student will be given thanks to his increased skill, must also increase. More precisely, scaffolding implies a coupling between two changing levels: the level of competence embodied in the student on the one hand, and the level of competence embodied in the level of scaffolding.

These six aspects refer to two basic components in the model, one consisting of the levels that can change, and the other consisting of mechanism that makes the level change.

To begin with, the level of the student's skill and the level of the support are described in terms of the same variable or ''ruler'' (Fischer & Dawson, 2002; Fischer & Rose, 1994; Rose & Fischer, 1998). This ruler or variable specifies the differences in levels within a student, between students, or between a scaffold and a student's current competence.

In our research project, which focuses on the math class, the ruler was chosen on highly pragmatical grounds. The ruler we chose is in fact the math workbook of the math curriculum used in the current class, consisting of a great number of separate tasks, ordered on the basis of mathematical complexity. Thus, the child's unaided or independent level of math skill can, for convenience, be described as the point in the workbook where he can solve the tasks without help. The scaffold level is some further point in the workbook, where the tasks can be solved thanks to the scaffold or help. The pupil's learning rate is then inferred on the basis of the time the pupil needs to achieve the skill that will allow him to do these more difficult tasks without help. The mechanisms that explain changes in these levels have been described in Vygotsky's notion of the zone of proximal development (Vygotsky, 1978), which implies that, over time, the student will interiorize the help given to him in such a way that his skill is advanced towards the level incorporated in the teacher's past scaffolding (for a dynamic model of this process, see van Geert, 1994b).

2. A classical dynamic systems model of scaffolding

2.1. General properties of the model

With these two components we have arrived at the conceptual core of a classical dynamic systems model of scaffolding. A basic property of a classical dynamic systems model is that it reduces complex systems to the smallest possible set of properties, needed to describe the system in question in terms of its barest essentials. The model intends to answer the question: what happens with the pupil's (math competence) level over time, what happens with the scaffold level over time, and how are these two related to one another over time?

First, it is clear that the conceptual model as sketched in the preceding section is a *dynamic* model, since it describes a transformation of a ''state'' (one math competence level) into another such state.

A second important aspect is that the dynamic model of scaffolding is a *coupled* dynamic model. We have seen that the level of the pupil will determine the level of the scaffold (which should be ahead of the first), while the level of the scaffold will determine the level of the pupil (which will move towards the level embodied in the scaffolding).

Third, at this point, the dynamic system still lacks a property that a dynamics is likely to have if it is going to be truly dynamic, or useful for that matter. That property is *iterativeness* or recursiveness. The scaffolding dynamics will lead to a competence level in the pupil that, ideally, resembles the competence level embodied in the preceding scaffolding. However, this new level of skill of the student is likely to be put to the test in new, more complicated tasks or problems, where it is likely to require new support. This repeated application of the scaffolding dynamics is what is called iterativeness or recursiveness, where the result (or "output") of a scaffolding process forms the input of a new one. Hence, the dynamic model simulates a sequence of steps in time, describing what is called the time evolution of the system's basic variables. In the current application to learning in the math class, a single step could be identified with a single help or scaffolding sequence of a particular pupil in the class.

2.2. Model parameters

In dynamic systems terms, the teacher's scaffold, more precisely, the competence level embodied in that scaffold, is an *attractor* for the pupil's current level (the pupil's level moves towards that of the teacher). The teacher's scaffolding level will tend to stay ahead of the pupil's competence level, i.e. the student's competence level is a *repellor* for the teacher's help level (the teacher's level moves away from that of the pupil).

As to the pupil, there exist two important parameters that govern this movement towards the attractor, first, the *learning rate* and second the *optimal scaffolding distance.* The change in the teacher's help level is governed by a third parameter, the *demand-adaptation rate*. The values of these parameters are person- and context-specific (e.g. a particular pupil in the context of the math curriculuim).

2.2.1. The learning rate parameter

This parameter determines the speed with which the attractor level is reached. It is related to psychological variables such as general intelligence, domain-specific intelligence or knowledge, motivation, and so forth. Thus, one way to incorporate, for instance, differences in intelligence or motivation between pupils in the model is to run the model with different change-rates or learning-rates. In the Vygotskyan model of the Zone-of-Proximal-Development, the learning takes the form of an interiorization mechanism (Lawrence & Valsiner, 1993; Valsiner & Van der Veer, 1999). The current dynamic model makes no particular claim, however, about the exact nature of the underlying mechanism.

2.2.2. The optimal scaffolding distance parameter

The second parameter can best be introduced by means of an example. For instance, if pupil B needs help with his math tasks, the teacher will tend to refer to relatively general mathematical working principles, because she knows from previous experiences, intuition, reactions from pupil B that this is the sort of help that works best with B. This type of help implies a relatively big distance from the pupil's current competence level. With pupil A, however, the teacher tends to lead the pupil through all the concrete steps he has to make in order to solve the task. This type of help is considerably closer to the pupil's current level than the help in the form of more general recommendations or principles. In short, there seems to exist a distance between the pupil's level and the level of help or scaffolding, for which the learning effect is maximal. This is the optimal scaffolding distance, or optimal distance for short. More technically speaking, there exists a certain bandwidth, which differs among individuals and contexts, within which help is functional, i.e. within which help stimulates learning.

Let us now, by way of thought experiment, begin with a level of help that coincides with the pupil's current competence level (i.e. the competence-help distance is 0). It is clear that this "help" will not stimulate any learning, since it contains nothing the pupil does not already know (i.e. the effect of help is nil). Let us now gradually increase this distance. We will, by definition, reach a point where the distance is optimal, i.e. where the learning effect of the help is maximal. If we further increase the distance, we must reach a point where the difference between the pupil's own competence and the help becomes so great that help is no longer effective. That is, the effect of help will be nil. The distance at which this occurs is called the maximal distance or m. It is clear that help will remain ineffective for all greater distances. Hence, the distance between distance 0 and distance m specifies a bandwidth of scaffolding within which scaffolding is effective, i.e. stimulates learning. The optimal scaffolding level, for which learning is maximal under the concrete circumstances given, lies within this bandwidth.[2] The optimal help distance, as the learning rate, depends on various psychological variables, for instance on domain-specific intelligence.

2.2.3. The demand-adaptation-rate parameter

It is easy to see that scaffolding or help on the one hand and the curriculum demands on the other hand, are directly related. If a pupil is given a difficult math task relative to his competence, then considerably more help is required to make him succeed on the task than with an easy task or assignment. However, scaffolding, giving help and support, requires time and effort, and time and effort are limited resources in a class. Let us now assume that a particular pupil has successfully interiorized the help given to him previously and succeeds in doing independently what, before, still required the help of the teacher. At this point, the teacher will set a new task to the student, e.g. to make the next assignment in the math workbook. A crucial question—which is also a crucial question behind the design of curricula and workbooks—considers the distance between the previous assignment, which the student is supposed to have mastered, and the new assignment. If you think about the curriculum as a staircase, the current question refers to the height of the steps.

If we take the metaphor of the staircase literally, the steps will have a similar size, and thus the intended curriculum progress is equal to adding a constant (one climbs the staircase one step at a time). In the dynamic model, however, the step sizes are proportional to the competence level already attained in the curriculum. Thus, the increase in the demand level is governed by a rate parameter, which we call the demand-adaptation-rate parameter. A more difficult curriculum would thus be characterized by a higher demand-adaptation-rate parameter than an easy one.

2.3. Differences in model parameters: an application in the math class

In the math class that the current authors are studying longitudinally, all children follow the same math curriculum, use the same workbooks and thus make the same assignments. However, children work on different levels of the workbook, dependent on their math competence. Hence, the speed with which they move through their math workbook is an individual variable.

[2]In the model, the level of scaffolding or help is always proportional to the pupil's independent level L. Hence, the level at which scaffolding or help is no longer effective equals $L(1+m)$. It can be mathematically shown that the optimal level of help or scaffolding, for which the learning effect is maximal is equal to $L\sqrt{(1+m)}$.

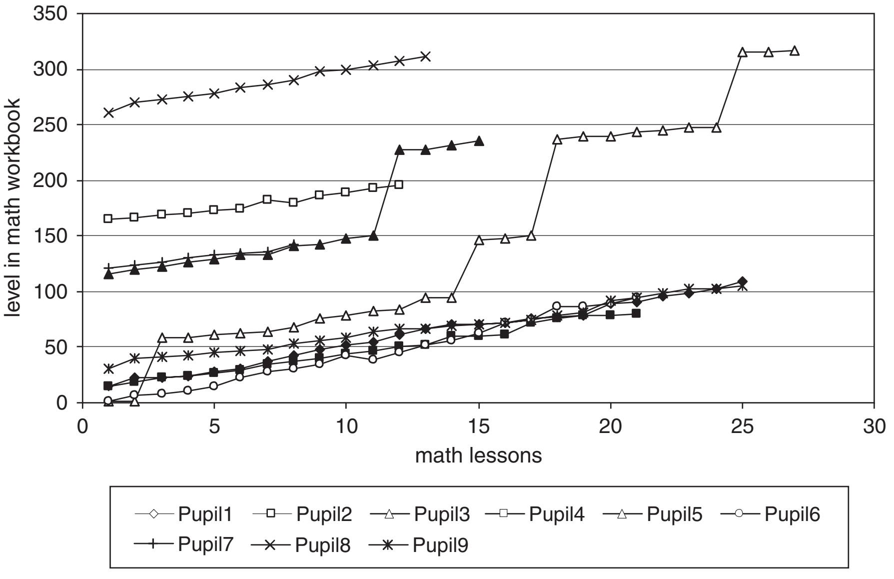

Fig. 1. Progress of nine pupils through the math workbook over a number of consecutive lessons.

Fig. 1, which shows the progress of the nine pupils of the class through the math workbook over a period of 4 months, will be used to demonstrate some of the possible parameter differences. Note that in the present math class, children are asked to make as many tasks as possible during a lesson. If the pupils encounter difficulties they can receive help and make a few sums from the assignment in question together with the teacher, and then proceed with doing the rest of the sums on their own. Thus, the graphs represent the *scaffolded level* of the pupils' math competence, as defined through the math workbook.

The difference between the least and the most advanced pupil is considerable (about 250 tasks, compare for instance the task level at the first lesson). Most of the curves show simple linear progressions, with slopes that appear quite similar. This suggests that the learning rates (basically, how much new math a pupil incorporates over time) are quite similar across pupils. Two children, whom the teacher considers good in math, are sometimes allowed to skip assignment blocks (comprising about 50–75 tasks). The teacher estimates the children's competence by informally monitoring the level of independent successful math problem solving. For these two children, the teacher implicitly applies a variable *rate of demand adaptation*, which is sometimes equal to that she applies to the rest of the pupils, and sometimes considerably greater. The fact that these children do not slow down in performance after the greater step, suggests that their learning rate lies higher than what can be inferred on the basis of their actual performance (the number of assignments made).

At the moment of this writing, for five children three consecutive math lessons have been coded for the variables on-task and off-task behavior, waiting for help and getting help. The results of the coding suggest that there are considerable differences between the children in the amount of help they ask and receive. For instance, a pupil with high math competence who is allowed to skip assignment blocks, receives little scaffolding, in comparison with his fellow pupils, shows a great amount of on-task but also a great amount of off-task behavior. The duration and frequency of scaffolding by the teacher is inversely related to the competence level of the pupil in question and is also inversely related to the amount of time the pupil invests in working alone. Another pupil spends quite some time waiting for and receiving help and relatively little on-task and off-task behavior. We assume that these patterns are self-sustaining and that they relate in some complicated and not yet clarified way to the parameters of the learning-and-scaffolding dynamics.

2.4. Formal model: structure and properties

Given the components discussed, the dynamics of scaffolding can be described in the form of a coupled equations model (Fig. 2).

The first equation in Fig. 2 describes the change in a student's level of skill or knowledge, the change is represented by ΔL, and depends among others, on the level of the help given,

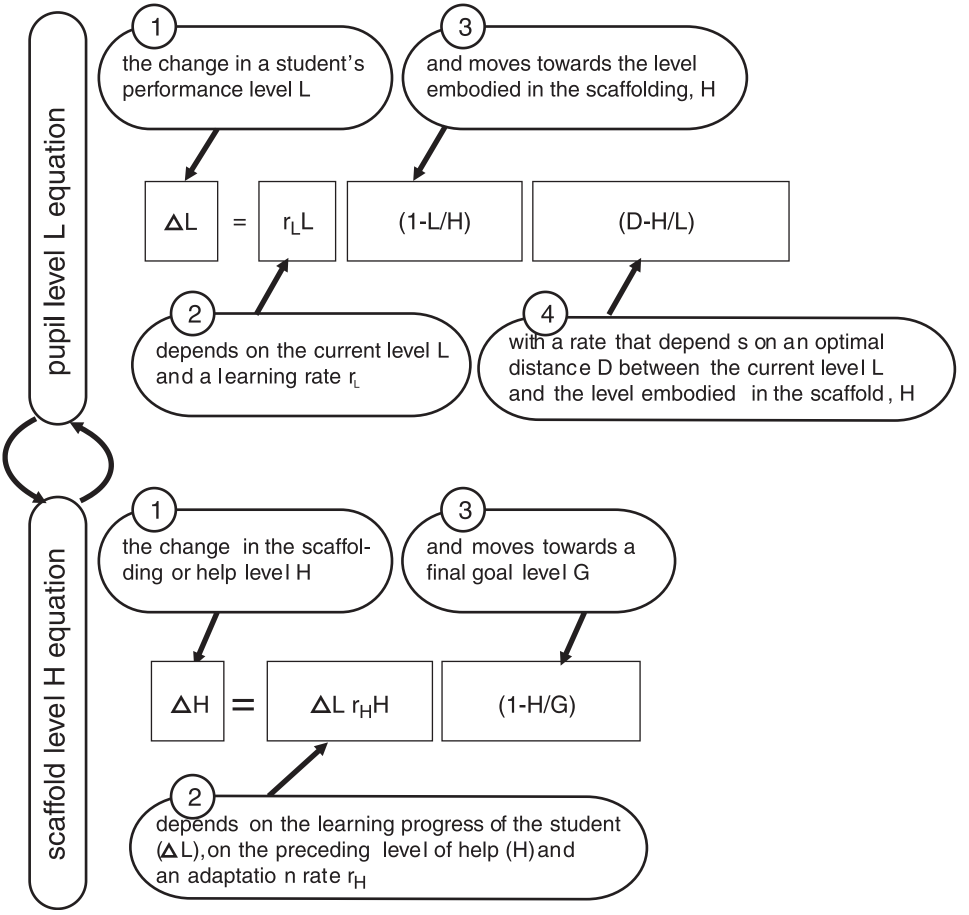

Fig. 2. Mathematical dynamic model of scaffolded learning, with an explanation of the equation components.

expressed by the symbol H. The second equation describes the change in a teacher's level of help or scaffolding given, ΔH, which depends, among others, on the pupil's learning, i.e. the progress made in the competence level, ΔL (see Fig. 2 for a further explanation of the components of the equations).

The assumption that the change in help depends on the progress made by the pupil, implies that the teacher must not monitor the pupil's factual competence level (which would be a very difficult task to accomplish), but that she must monitor the student's progress following the help she is giving. This relative assessment is, most likely, considerably easier to make. In order to be able to make this assessment, the pupil must be given the opportunity to independently work on his math tasks and thus to show the extent to which the help has contributed to his skill.

The mathematical model of scaffolding and learning described in Fig. 2 produces a variety of qualitatively different patterns, depending on the values of the parameters. Empirically observable differences between children and between teachers can be described by particular parameter values. For instance, low learning rates combined with low optimal distances represent pupils that have low potentialities regarding the curriculum or the learning content in question. In short, any combination of parameter values implicitly refers to a possible empirical case and thus predicts the sort of (idealized) learning-and-scaffolding pattern that will occur in this case (An implementation of the mathematical model in the form of an Excel file can be downloaded at www.vangeert.nl/link to Research and Dynamic Systems Models, A Model of Learning and Teaching.xls).

The first step in the calibration of a dynamic model is to find the parameter values that produce a trajectory that one considers as the normal or expected, i.e. the default case. The expected pattern in a process of learning and teaching should be one of attaining the final goal state after a particular number of learning-and-teaching events, for instance 200 math lessons which cover approximately a school year. The model predicts that such ideal, expected trajectory takes the form of an S-shaped curve (Fig. 3).

The help or scaffolding level and the pupil's level of independent competence (what he can do without help) are specified in terms of the same underlying variable, the learning content, represented on the vertical axis. Consistent with the case presented in the article, the underlying variable is pragmatically defined as the student's math workbook. The help or scaffolding level runs ahead of the pupil's competence, until both reach the final goal of the curriculum. Note that the scaffolding level runs farther ahead from the pupil's level around the middle of the learning trajectory. In order to obtain an idea of what this running ahead actually means, take the help level at an arbitrarily chosen time point (e.g. 141). This level is at the same height as the pupil's independent level at time point 161. This means that the help at time 141 embodies a level of understanding the student will have incorporated in about 20 steps (e.g. 20 lessons, 20 scaffold events, …). For a good understanding of the model and the curves it generates, it is essential to take the model's iterative nature into account. That is, anything that happens at some point in time in the pupil affects something in the scaffolding activity of the teacher, and anything that happens in the scaffolding activity of the teacher affects something in the teacher. That is, the curves—for instance the teacher's scaffolding curve—should not be viewed as the representation of some independent process that drags a dependent process, the pupil's competence, towards some end state. Whatever happens in the scaffolding and learning is a deeply transactional process.

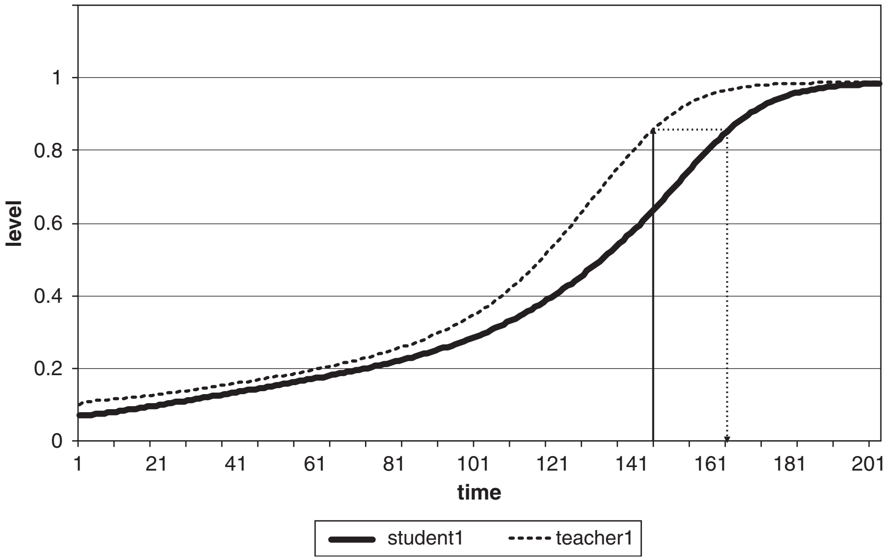

Fig. 3. An ideal trajectory of scaffolded learning: the teaching level (dotted line) stays ahead of the learning level.

One interesting consequence of the model is that, within certain limits, for any set of learning rate and optimal distance values (the pupil parameters), there exists a range of demand-adaptation values (the curriculum parameter) that will lead the system to reaching the final goal state. More concretely, for any pupil there exists a range of curricula that are neither too easy nor too difficult and will lead to successful learning in this pupil. Note that these curricula are distinguished on the basis of the type of scaffolding they present.

The pessimistic part of the message, however, lies in the specification ‘‘within certain limits’’. The model predicts that for certain combinations of pupil characteristics (basically the lower end of the spectrum of values), any curriculum will stabilize at a learning result in the pupil that is well below the final goal level (see Fig. 4).

However, the model also predicts that such a sub-optimal patterns can be overcome by means of adaptive scaffolding, in which the teacher actively seeks for new and more effective forms of scaffolding a particular pupil. For instance, the teacher may try to go back to earlier skill components, and move closer towards the pupil's actual competence level, which requires an adequate ‘‘on-line’’ assessment of that level.

One other model prediction that is of interest in the current context of application, is that for less-talented learners, long-term course of the learning and scaffolding process is very sensitive to the initial state properties, that is, they are very sensitive to the sort of scaffolding given at the beginning of the curriculum.

As noted earlier, the optimal distance parameter determines which type of scaffolding is optimally adapted to a particular pupil's learning potentials. The model predicts a strongly non-linear relationship, however, between the optimal distance and the final learning effect of a curriculum.

Fig. 5 shows, among others, that very small distances (scaffolding staying very close to the pupil's independent competence level) can also be quite effective, from the point of view of learning results. It is likely that this sort of scaffolding corresponds with self-

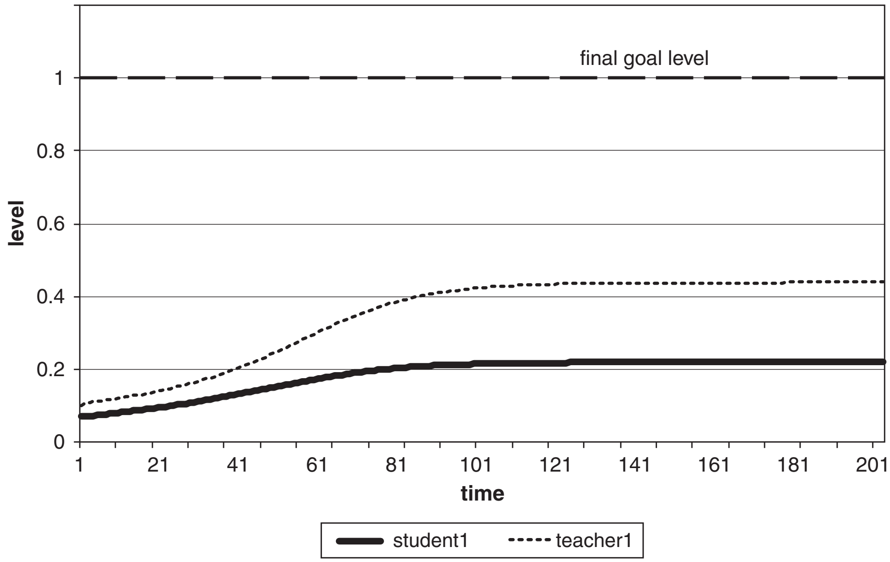

Fig. 4. A sub-optimal process of scaffolded learning, in which the learning- and teaching levels keep each other stabilized at a level far below the final goal level.

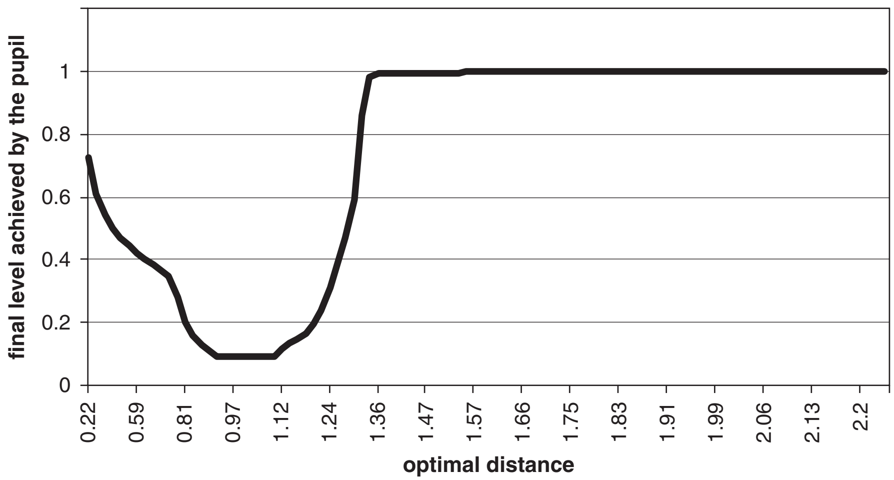

Fig. 5. The non-linear relationship between optimal distance and final stabilized level of the scaffolded learning process.

scaffolding, which occurs in a "fringe of change" that runs just a little ahead of one's current, consolidated competence level (van Geert, 1998a, b).

3. Towards an embodied and socially situated dynamics of scaffolding

3.1. Concerns, emotions and actions

In spite of its great simplicity, the dynamic model displayed a variety of qualitatively different patterns and properties. However, just as a classical dynamic systems model of population growth, for instance, shows us the basic dynamics of population growth or decline, but does not specify the more detailed mechanisms of the birth and death of individuals, the current dynamics of scaffolding and help needs to be supplemented by a more detailed model of the underlying mechanisms. In our view, such a more detailed model must, in the first place, describe how these basic dynamics are embodied and how they are socially situated (Steenbeek, 2006; Steenbeek and van Geert, 2005; Van Geert and Steenbeek, 2005). That is, both learning and scaffolding (teaching and helping) are acts of embodied, socially situated agents, namely pupils and teachers. Their acts are primarily governed by their concerns, that is, by their intentions, goals, or interests. They continuously evaluate the contexts, which they themselves help to create and maintain, against their concerns, which they try to realize through these acts and in these contexts. These evaluations and their emotional expressions help determine their own actions and those of the people with whom they interact. Concerns and goals are deeply social, that is, co-determined by the concerns and evaluations of other persons.

For instance, in the math class the default concern for the pupil should ideally be the pupil's wish to do the required math for half an hour and by doing so improve his math skills. For the teacher, the default concern should ideally be to make the students do the math and help them improve their math skills, against the backdrop of a particular math curriculum, workbooks, etc. However, in the class that begins at 8:30 in the morning, an important concern of the children (many of whom have boarded the school bus around 7:30) may be to just doze off or rest. Another such concern may be to talk and socialize with friends, or to have the positive attention of the teacher. These concerns are dynamically interrelated. Some support each other, such as doing the math and have the attention and time of the teacher, whereas others stand in a competitive relationship, such as chat with friends and have the approval of the teacher. Some concerns may even show a "parasitic" relationship. For instance, in the current class, pupils must ask for help from the teacher by turning a two-colored block with the green side up, and then wait until they are given the opportunity to obtain help from the teacher. In a busy class, this asking for help may serve two opposite concerns, namely to withdraw from the math activities and relax for a while, and at the same time showing interest in the math and getting positive support and attention from the teacher.

3.2. Constraints

In order to understand the dynamics resulting from this agent model, we need to specify a number of constraints, that is, situation-specific restrictions that co-determine what will happen in that situation. The class that we observe concerns children in special education with behavioral and psychiatric problems. A typical constraint that applies to these children concerns the issue of discipline in the class. The teachers regularly experience that situations very easily get out of hand if order and quiet are not well maintained. Another constraint is the great sensitivity the children have for negative appraisals, which, the teachers feel, should be avoided where possible. Yet another constraint is the relative rigidity of these children, i.e. their inability to flexibly switch from one task to another and back. Thus, children are required to finish a particular assignment before beginning another one. Sometimes they need help to make the assignment, and if the teacher is giving help to another pupil, they have to wait their turn. In children who require much help, this can eventually lead to a considerable loss of time, which must be balanced against the risk of the pupil becoming too distracted and disorganized by working on more than one assignment at a time.

The constraints are dynamically related. They set limits to the possible actions of both teachers and pupils and thus may eventually contribute to maintaining sub-optimal equilibria of scaffolding and learning.

4. Summary and prospects

In this article we have reinterpreted a relatively standard definition of scaffolding in the context of dynamic systems theory, which resulted in a dynamic model of scaffolded learning. We have illustrated the model with a time-serial study of the math learning of five children in a school for special education. The aim of this study, which is now in its starting phase, is to empirically validate the dynamic model and to further elaborate on the socially situated nature of the learning and scaffolding activities of pupils and teachers. It is our belief that a better understanding of the dynamics of the process of learning and teaching requires studies of socially situated individual processes, on the short-term time scale of a single lesson or scaffolding event as well as on the long-term time scale of the acquisition of skills and knowledge. For instance, how does a particular child's short-term goal of getting attention from the teacher during a lesson relate to the short-term process of making math assignments and asking help, and to the long-term process of math learning and mathematical skill acquisition?

Aided by the building of dynamic models that simulate possible trajectories of teaching and learning, empirical studies must focus on the principles that govern the dynamics on these different time scales and on the way these time scales are connected.

By combining dynamic model building with empirical studies, insight can be obtained in the dynamics of problematic learning and teaching trajectories. These insights can hopefully be transformed into functional rules-of-thumb that may help teachers to optimally support learning in this particular group of pupils, through scaffolding that reckons with the particular dynamics of the learning process in question.

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