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# Analysing students' shared activity while modeling a biological process in a computer-supported educational environment

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**Abstract** This paper reports on a case study with three dyads of high school students (age 14 years) each collaborating on a plant growth modeling task in the computer-supported educational environment '*ModelsCreator*'. Following a qualitative line of research, the present study aims at highlighting the ways in which the collaborating students as well as the facilitator who supported them are engaged in the computer-based modeling 'activity'. The analysis is carried out with a two-level analytic tool that has been derived within the theoretical framework of 'activity theory'. Our results show that a wide range of modeling 'operations' is activated in the context of the three major modeling 'actions' of 'analysis', 'synthesis' and 'testing-interpreting', which take place in the light of the facilitator-driven 'action' of cognitive and technical support. Moreover, these actions are combined into 'modeling units' of various forms which are repeated several times until the modeling process comes to an end. These many-fold repeats of the 'modeling unit' appear to shape a pattern which characterizes the computer-supported shared 'activity' as a whole.

**Keywords** collaborative modeling, computer-supported modeling, modeling activity, modeling patterns.

## Introduction

Modeling, which is well established as a core activity of the scientific enterprise itself (Giere 1991), has also been identified as a quite promising tool for teaching and learning science (Gilbert & Boulter 1998). The educational value of modeling can be grounded either within the theoretical framework of 'situated learning' and the associated notion of students' 'cognitive apprenticeship' in scientists' 'authentic' practices and tools (Brown *et al.* 1989), or upon the more cognitively oriented notion that learning is based on a process of mental model building (Johnson-Laird 1983).

Mental models are internal cognitive representations of objects, events, processes or systems, built by individuals while working on their own or participating in collaborative situations (Gilbert & Boulter 2000). These internal representations provide students with ways of reasoning about the natural world. Thus, they shape a framework within which students may produce external representations for shared reasoning and problem-solving. Known as 'expressed models', these external representations may have some quite different forms such as, for instance, oral speech, written texts, concept maps or dynamic models (Buckley 2000).

Students' mental models do influence the construction of expressed models. But more importantly, the same seems to be valid *vice versa*: the relationship between mental and expressed models is characterized as bidirectional (Gilbert & Boulter 2000). In other words, by creating expressed models and reflecting on

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them, students may come up with possibly significant elaborations of the underlying mental models (Johnson-Laird 1983). Thus, constructing expressed models may support mental model building and lead to personal understanding, meaning making and learning (Perkins 1986).

Despite the fact that model-based learning has been acknowledged as a key area in science education research (Clement 2000), there is still no theory to provide us with a coherent overview of the cognitive processes through which this kind of learning is carried out and the teaching support that it possibly requires (Gobert & Buckley 2000). Attempting to develop such a theory on how the elaboration of mental models may be triggered, performed and supported within a process of constructing expressed models, requires actually a better understanding of this process itself. It is worth noticing that the latter may have some quite different features depending on the form of the expressed model under construction as well as on the environment within which this construction is performed and the tools that are used (Löhner *et al*. 2003; Komis *et al*. 2006).

Constructing external representations in the form of dynamic models is actually possible due to a series of computer-supported learning environments that have been developed in the last few decades (Steed 1992; Kurtz dos Santos & Ogborn 1994; Jackson *et al*. 1996; Ogborn 1998; Dimitracopoulou *et al*. 1999; Dimitracopoulou & Komis 2005; van Joolingen *et al*. 2005). Including adequate building and testing tools, such environments give learners the opportunity not only to express certain aspects of their internal representations about the natural world but also to explore and possibly reflect on the behaviour of these expressed models on the basis of the dynamic output they gain while manipulating any structural or functional element of the model they wish (Soloway *et al*. 1994; Stratford *et al*. 1998). The dynamic character of such external representations may possibly become of key importance for meaningful understanding and learning (Kurtz dos Santos & Ogborn 1994), which in turn has made the study of the process towards them particularly interesting (Stratford 1997).

Setting the focus exclusively on computer-supported dynamic modeling, Stratford *et al*. (1998) have thoroughly discussed a series of associated cognitive strategies such as analysis, relational reasoning, synthesis, testing-debugging and explaining. Nevertheless, an even more systematic microanalysis of such strategies that could be further combined with a possible synthesis of them on the level of modeling patterns would rather make an interesting contribution towards a better understanding of the process of dynamic modeling. The present study is actually engaged in both while attempting to highlight dynamic modeling within the computer-supported environment *ModelsCreator*.

*ModelsCreator* belongs to a special category of modeling environments that allow for semi-quantitative reasoning (Bliss 1994) without the need for using formal mathematics (Komis *et al*. 2001). Learners are supposed to reason in terms of 'objects' that stand for task-bound concepts, 'properties' that stand for specific parameters of the 'objects' involved and finally semi-quantitatively expressed 'relationships' between the 'properties' of one or more 'objects'. This possibly facilitates a gradual transition from the spontaneously expressed qualitative reasoning to the much more demanding quantitative reasoning (Ogborn 1998). Furthermore, providing visual representations of 'objects' and 'properties' as well as simulations of their behaviour while being part of certain 'relationships' may be supportive for young learners who possibly encounter significant difficulties with abstract reasoning (Dimitracopoulou *et al*. 1999). Related also with testing the expressed models, this visualization may contribute rather significantly to a more meaningful and effective exploration of the modeling task.

The present study attempts to analyse the modeling process of students working with *ModelsCreator*. The questions addressed here are the following:

- How do collaborating students perform higher-level modeling 'actions' through lower-level modeling 'operations'?
- How does the facilitator support each 'action'?
- Does the performance of the 'actions' follow a pattern that could possibly characterize the modeling activity as a whole?

So, the objective of the study is to reconstruct first the higher-level cognitive actions through the underlying modeling operations and then the whole activity through any possible patterns upon which these cognitive actions seem to be performed; in other words, to model the shared activity – which takes place within a computer-supported modeling environment – with a set of modeling actions carried out through a subset of modeling operations.

## Method

### The setting

This case study took place in a laboratory of human–computer interaction of the University of Patras. The participants were three dyads of high school students (age 14 years) randomly selected from a typical class of a public high school in the rural area of Patras. Four of the participating students were female (Dyads I and III), while two of them were male (Dyad II). Moreover, the school performance of Dyad I was good, while that of Dyads II and III was average. Each of the three dyads – cognitively and technically supported by a facilitator – collaboratively modeled the biological process of plant growth within the computer-supported educational environment *ModelsCreator*.

In this setting, the facilitator was supposed to provide students with specific information on how to use software tools in the modeling process, as well as with cognitive support, but not with ready-made answers. Moreover, peers were supposed to pursue the common goal of creating joint models through a collaborative, competition-free, interactional process. The role of the actors was discussed at the outset of the modeling process.

After a 10-min demonstration of *ModelsCreator,* the students were asked to 'create a dynamic model describing the environmental factors interfering with plant growth and explaining the way in which each of them does so'. The task actually requires shifting reasoning between the macro-level of environmental factors and the micro-level of the biochemical process of photosynthesis. This is quite demanding although the participating peers had already been lectured on photosynthesis and plant growth.

*ModelsCreator* provides students with a set of five objects and a subset of several properties for each object:

- Plant: growth/food/energy
- Soil: water/minerals
- Sun: light/warmth
- Air: oxygen/carbon dioxide
- Leaf: carbon dioxide/water/photosynthesis/glucose/oxygen

Furthermore, there is a set of semi-quantitative relationships (i.e. 'increases–increases', 'increases–decreases' or 'increases–increases less') upon which students draw to establish links among selected structural parts in a quantitatively informed, but still qualitative manner. For instance, a link between soil water and plant growth – possibly warranted upon the idea that 'the water contributes to plant growth' – can be made by inserting the 'increases–increases' relationship, which is interpreted rather qualitatively: 'there must be plenty of water available in the soil, to have plenty of plant growth taking place'.

Peers create models by selecting objects, moving them in the working space, selecting properties for each object (the visual representation of which is accordingly changed) and finally connecting the properties with relationships selected from the given set. The software generates log-files and also keeps the final models (Fig 1).

The three dyads agreed upon videotaping the modeling activity, the mean duration of which was approximately 45 min. Each of the three videos was initially synchronized with the actors' operations and then transcribed. The transcripts were segmented into message units (Kelly *et al*. 1998), each possibly representing an actor's verbal (utterance) or practical (handling) modeling operation. Finally, the segmented transcripts were analysed with the emerging coding scheme. All the coding was performed independently by one of the authors as well as by a second researcher and the resulting value for Cohen's Kappa was 0.94.

### The analytic tool

To develop a functional coding scheme for analysing our data, we drew upon three different analytical frameworks:

- The 'Object-oriented Collaboration Analysis Framework'– 'OCAF' (Avouris *et al*. 2003), which instead of focusing as usual on the actors who develop a shared solution, is particularly concerned with the very objects that structurally shape this solution.
- The 'Flow of discourse analytical framework' (Mortimor & Scott 2000) which focuses on the form

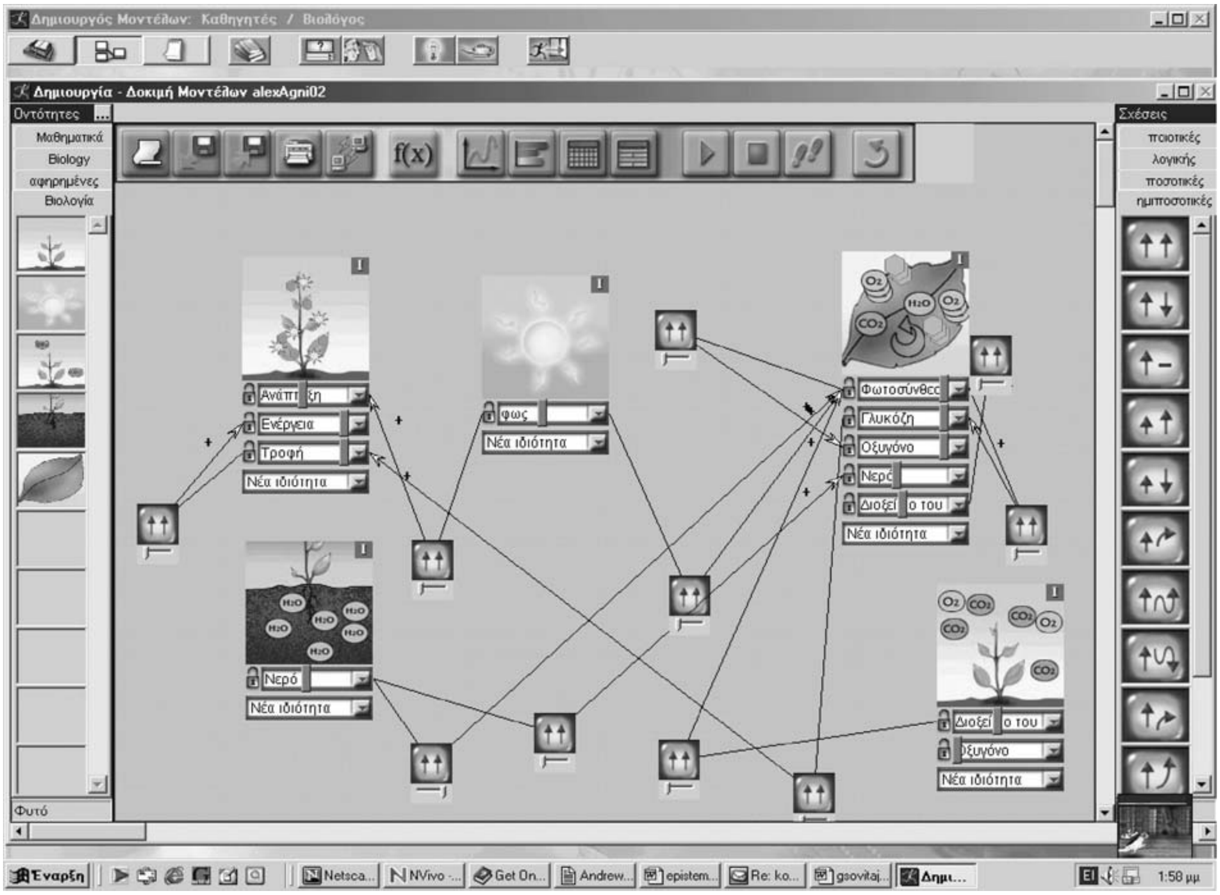

Fig 1 A plant growth model within '*ModelsCreator*'.

of teachers' interventions in the flow of educational discourse.

- The 'Cognitive Strategies for Modeling' or 'CSM' scheme (Stratford *et al*. 1998) which identifies five cognitive strategies in dynamic modeling: analysing, relational reasoning, synthesizing, testing-debugging and explaining.

Elaborating the OCAF and subsequently integrating it with the 'Flow of discourse analytical framework', we came up with a hybrid tool which, enriched with descriptors emerging from our own data, made it possible for us to fully describe not only the object-oriented modeling operations that peers perform but also the ones through which the facilitator engages in the action of 'cognitive & technical support' throughout the modeling process. Furthermore, viewing this deriving 32-category, low-level coding tool in the light of the CSM scheme of Stratford *et al*. (1998), we came up with three higher-level actions – analysis, synthesis, testing-interpreting – which may be supported by a fourth one, the facilitator-driven action of cognitive and technical support.

- ***Analysis (objects – properties):*** Selecting the appropriate structural elements for the model is associated with analysing the target phenomenon to its parts. Thus, the action of analysis is shaped by 11 operations having to do with objects and properties, either practically (exploring, selecting, inserting or deleting objects or properties and exploring object behaviour according to inserted properties) or verbally (arguing about objects or properties: justifying, challenging, conceding, opposing).
- ***Synthesis (relationships):*** Synthesizing the structural elements into meaningful model units through semi-quantitative relationships requires identifying not only which properties need to be linked, but also why

|  | Student A | Student B | Facilitator | Total | % |
|---|---|---|---|---|---|
| Analysis | 52 | 17 | 0 | 69 | 22.7 |
| Synthesis | 72 | 45 | 0 | 117 | 38.5 |
| Testing | 18 | 12 | 0 | 30 | 9.9 |
| Support | 20 | 8 | 60 | 88 | 28.9 |
| Total | 162 | 82 | 60 | 304 |  |

Table 1. Modeling operations per cognitive action and per actor (Dyad I).

and how. Thus, this action is shaped by eight operations concerning the parts of a relationship (selecting parts of a relationship, arguing about the parts, connection) or the type of a relationship (arguing about, describing, exploring, selecting, inserting and deleting relationships).

- ***Testing and interpreting:*** This modeling action is shaped by operations of requesting or performing tests of model behaviour with built-in testing tools (testing model behaviour) and discussing about it (making comments on model behaviour).
- ***Cognitive and technical support:*** Each of the previous actions may require supportive operations in order to become possible. Technical support has to do with using the software tools (involved in technical support). On the other hand, cognitive support consists either in direct information about the subject or the modeling task (involved in task support, involved in subject information exchange) or in the conceptually or procedurally oriented scaffolding that the facilitator sets for peers (shaping ideas, marking key ideas, requiring modeling operations, giving feedback on modeling operations, promoting shared meaning, checking students understanding, re-focusing the modeling process, reviewing the modeling process).

## Results

Using the action level as level of reference for presenting our results, we report on specific features of the three major modeling actions identified in this study for all three dyads: (i) the proportion of the modeling actions within the overall activity, (ii) the collaboration they promote, (iii) their argumentative character, and finally (iv) the degree of support they require. Finally, we present the modeling pattern that these actions together compose.

Moreover, it is worth mentioning that the facilitator-supported shared activity can be schematically presented in a diagram where the vertical axis shows the modeling operations – verbal or practical – performed by each actor while the horizontal shows the time of their performance (Komis *et al*., 2006).

### Dyad I

Analysis represents almost 1/4 of the activity and peers are involved in it asymmetrically: student A contributes 75% of the action while student B only 25% (Table 1). Analysis does not appear to have a strong argumentative character: only a small part has to do with justifying, challenging, conceding, or opposing in regard with objects and properties (*arguing about an object* ×3 times *arguing about a property* ×7 times). Peers do not seem to need any cognitive support in analysing the target phenomenon: none of the relevant operations is activated within this action. On the contrary, 26% of the overall technical support is located here (*involved in technical support* ×10 times), particularly at the outset of the activity when peers are not yet confident enough with the software use.

Synthesis represents a greater part of the activity and peers show a more symmetrical engagement in it (Table 1). The argumentative character of synthesis is much stronger: 40% of it is carried out through justifying, challenging, conceding, or opposing relationships (*arguing about the parts connection* ×23 times*, arguing about a relationship* ×22 times).

Moreover, synthesis is the most cognitively supported action: 82% of the overall cognitive support is located here. Supportive operations such as *shaping ideas* through instructional questions or *marking key ideas* are exclusively activated within synthesis (10 times and 5 times, respectively). Similarly, the need of *promoting shared meaning* seems to emerge only in regard with the construction of relationships, while *giving feedback* has always to do with validating relational proposals (4 times and 2 times, respectively). Finally, *requiring modeling operations* as well as

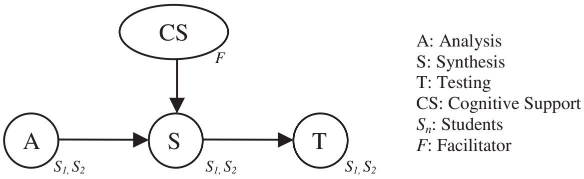

**Fig 2** The 'modeling unit'.

*checking students understanding* are mostly activated to support students in translating ideas to relationships (5 times and 4 times, respectively). In addition, more than half of the overall technical support has to do with manipulating relationships while involved in the action of synthesis, particularly at the outset of the activity: the operation *involved in technical support* is mobilized 22 times.

Testing and interpreting model behaviour represents the smallest part and students' participation is rather balanced (Table 1). The feature of argumentative character is not actually applicable here, as there are not any argumentative operations attributed to this action. Furthermore, half of this action has to do with merely running the model, while the other half includes rather descriptive than explanatory comments on model behaviour. Students' involvement in discussing model behaviour seems to be closely bound to the supportive operation of *checking students' understanding* about what is really observed during model run, which is activated 6 times.

Summarizing the action of cognitive and technical support itself, it should be noted that it constitutes a significant part of the activity (Table 1) and it is similarly shared on both cognitive and technical levels. The cognitive support is distributed among synthesis and testing-interpreting, with the former gathering a significantly greater part (82%). This actually may indicate that the action of synthesis is highly demanding for peers. Moreover, as already shown, the technical support, is distributed among all three actions (analysis: 26%, synthesis: 58%, testing: 14%) and its rather high occurrence may be attributed to the fact that peers have no previous experience with *ModelsCreator*. This is also suggested by the total absence of technical support in the second half of the activity.

Our results show that the modeling activity follows a pattern of repeated, facilitator-supported, three-action 'modeling units' of various forms. Including the three major modeling actions of analysis, synthesis and testing sequentially performed (Fig 2), a modeling unit could actually be enough for completing the modeling process. Nevertheless, it seems that there is a need of repeating the modeling unit several times until the construction of the model comes to an end (see five repeats in Fig 3). Moreover, it seems that there is a need for non-linear shifts between the in-unit actions; in other words, a need for in-unit loops that consist of back and forth shifts either between the actions of analysis and synthesis or between the actions of synthesis and testing. This results in the process-related variations of the modeling unit depicted in Fig 4.

More specifically, unlike modeling units 1, 4 and 5 within which *any* two successive actions appear clearly separated in terms of time, modeling units 2 and 3 show

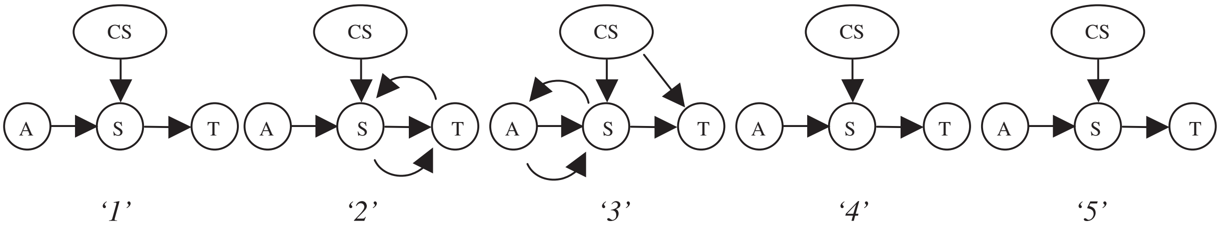

**Fig 3** The modeling pattern in the activity of Dyad I ('1'–'5': repeated 'modeling units').

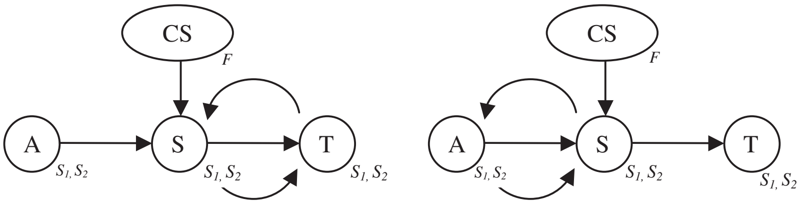

**Fig 4** The variations of the 'modeling unit'.

in-unit loops, which indicates that certain modeling actions seem as running in parallel (Fig 3). Extra variations also occur in regard with the distribution of cognitive support among the three actions. This is the case with modeling unit 3, where cognitive support appears to concern both the actions of synthesis and testing (Fig 3).

Finally, the action of analysis appears to be gradually decreasing from unit to unit in the activity of Dyad I, while the action of synthesis gives a reverse view at least up to a point. In fact, a bottom-up approach to the modeling task is probably indicated, as peers seem to first focus on objects and properties and *only later* shift interest in relational reasoning to start assembling them.

### Dyad II

Analysis represents 1/5 of the activity and peers' involvement in it is clearly asymmetrical (Table 2). This action does not seem to require either arguing or cognitive support for Dyad II. In fact, the relevant argumentative operations are not activated at all, while only an insignificant part of the cognitive support has to do with objects and properties. On the contrary, the greatest part of the technical support is located within this action throughout the activity (*involved in technical support* ×35 times).

Synthesis represents more than 1/3 of the activity and peers are engaged in it almost symmetrically, like their mates in Dyad I (Table 2). Synthesis – unlike analysis – shows an argumentative character, although not a very strong one: 22% of the action is carried out through justifying, challenging, conceding or opposing regarding relationships (*arguing about the parts*' *connection* ×9 times, *arguing about a relationship* ×18 times).

Moreover, synthesis is the most cognitively supported action: 90.5% of the overall cognitive support is located here. Significant supportive operations appear to be either exclusively or mostly activated within the action of synthesis: *shaping ideas* ×14 times*, marking key ideas* ×8 times*, promoting shared meaning* ×7 times*, checking students understanding* ×4 times or *reviewing the modeling process* ×16 times and *refocusing the modeling process* ×3 times. Similarly, much of the translation of ideas into model relationships is based on the facilitator's explicit requirement for performing appropriate operations (*requiring modeling operations* ×10 times) or on her validating/discounting feedback about relational proposals (*giving feedback on modeling operations* ×8 times). Finally, 28% of the overall technical support is associated with manipulating relationships throughout the activity (*involved in technical support* ×15 times).

Testing and interpreting model behaviour corresponds to an extremely limited part of the activity and it is performed almost exclusively by student C (Table 2). Once more, students' involvement in testing and discussing model behaviour seems to be closely bound to supportive operations such as requiring testing and checking students' understanding about what is being observed during model run (3 times and 4 times, respectively). On the contrary, supportive operations of technical character are very rare here.

The action of cognitive and technical support constitutes a very large part of the activity (Table 2) and it has mostly to do with cognitive (64%) than technical (36%) issues. The primarily supported action on the cognitive level is indeed synthesis which holds 90.5% of the overall cognitive support, while testing-interpreting comes next with only 7.5%. This actually may indicate once more that the action of synthesis is highly demanding for peers. Finally, the technical support is distributed among all the other actions (analysis: 66%, synthesis: 28%, testing: 6%) and actually keeps appearing throughout the whole activity.

Dyad II shows the same modeling pattern as Dyad I by constructing a model through repeats of the modeling unit or the process-related variations of it (see three

| | Student C | Student D | Facilitator | Total | % |
|---|---|---|---|---|---|
| Analysis | 53 | 13 | 0 | 66 | 19.1 |
| Synthesis | 75 | 48 | 0 | 123 | 35.7 |
| Testing | 7 | 2 | 0 | 9 | 2.6 |
| Support | 28 | 16 | 103 | 147 | 42.6 |
| Total | 163 | 79 | 103 | 345 | |

Table 2. Modeling operations per cognitive action and per actor (Dyad II).

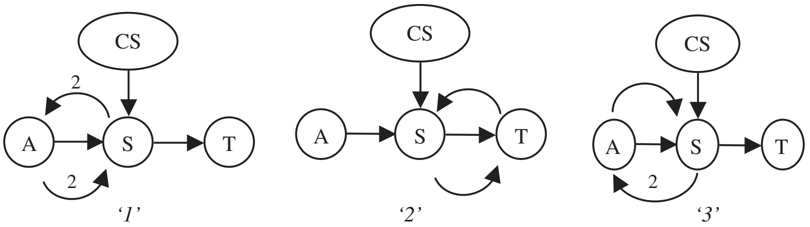

**Fig 5** The modeling pattern in the activity of Dyad II ('1'–'3': repeated modeling units).

**Table 3.** Modeling operations per cognitive action and per actor (Dyad III).

| | Student E | Student F | Facilitator | Total | % |
|---|---|---|---|---|---|
| Analysis | 63 | 29 | 0 | 92 | 30.7 |
| Synthesis | 56 | 26 | 0 | 82 | 27.3 |
| Testing | 13 | 7 | 0 | 20 | 6.7 |
| Support | 5 | 7 | 94 | 106 | 35.3 |
| Total | 137 | 69 | 94 | 300 | |

repeats in Fig 5). Moreover, in this case loops within units 1 and 3 derive from multiple shifts between the actions of analysis and synthesis before testing occurs.

Finally, the action of analysis is rather decreasing from unit to unit. In fact, in unit 1 it is very broad and appears to be interrupted by a respectively broad action of synthesis several times, before testing takes place for the first time (Fig 5). On the contrary, later on in the activity, analysis becomes much less extended similarly to what happened with Dyad I.

## Dyad III

Analysis represents the greatest part of the activity and peers are involved in it asymmetrically (Table 3). The argumentative character of this action is actually weak: only 6.5% of it has to do with justifying, challenging, conceding or opposing in regard with objects–properties (*arguing about an object* ×3 times, *arguing about a property* ×3 times). Unlike what happened with Dyads I and II, here a quite significant part of the overall cognitive support is located within analysis. In fact, analysis appears to be cognitively supported by the explicit requirement of the relevant building operations (3 times) and more importantly by conceptually oriented supportive operations such as *shaping ideas* and *marking key ideas* (11 times and 5 times, respectively). Moreover, analysis appears to be technically supported as well. In fact, more than half of the overall technical support has to do with manipulating objects and properties while analysing the target phenomenon. Although appearing throughout the activity, technical support starts fading as peers are getting more familiar with the use of the software.

Unlike what happened before, here synthesis holds a smaller part than analysis and peers' participation in it is asymmetrical (Table 3). The argumentative character of this action is stronger than that of the previous one, although it still remains rather weak: only 16% of it has to do with arguing about the parts or type of a relationship (*arguing about the parts*' *connection* ×12 times, *arguing about a relationship* ×1 time).

The performance of synthesis requires a significant part of the overall cognitive support. Supportive operations such as *shaping ideas* or *marking key ideas* – besides being performed to help students deconstruct the target phenomenon into its structural components – frequently provide them with a means for coping with the construction of relationships (8 times and 7 times, respectively). Similarly, synthesis is facilitated through checking students' understanding to clarify their ideas (2 times), requiring explicitly the transformation of theoretical ideas into subunits of the constructed model (8 times), providing feedback on relational proposals (10 times) and promoting shared meaning by requiring reflection on the ideas of the other (3 times). Finally, manipulating relationships appears to require only a very small part of the overall technical support (*involved in technical support* ×2 times).

Testing and interpreting model behaviour represents, once more, a limited part of the activity and peers are engaged in it rather asymmetrically (Table 3). Students'

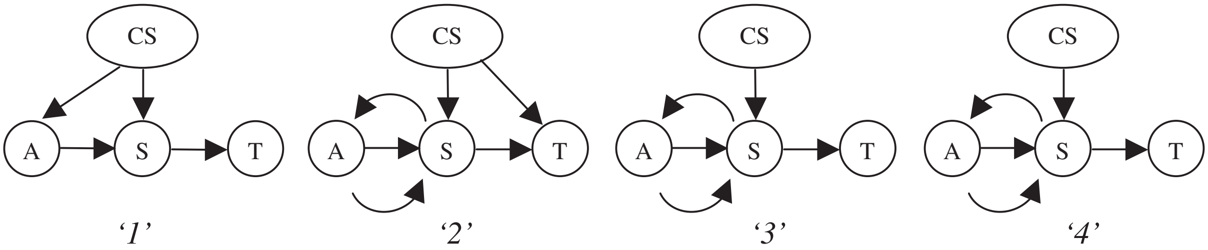

**Fig 6** The modeling pattern in the activity of Dyad III ('1'–'4': repeated modeling units).

involvement in testing and discussing model behaviour seems again to be strongly associated with the supportive operations of *requiring* testing and *checking students' understanding* about what is really observed during model run (2 times and 7 times, respectively). Furthermore, supportive operations of technical character are also activated here (*involved in technical support* ×8 times).

The action of cognitive and technical support constitutes a quite large part of the activity (Table 3) and it has more to do with cognitive (73.5%) than with technical (26.5%) issues. The primarily supported action on the cognitive level is indeed synthesis which holds 61% of the overall cognitive support, while analysing and testing-interpreting are coming next with 27% and 12% respectively. Moreover, technical support – as already shown – is distributed among all three actions (analysis: 64.3%, synthesis: 7.2%, testing: 28.5%) and keeps appearing throughout the activity – although less and less.

Dyad III shows the same modeling pattern as the first two dyads. As summarized in Fig 6, our last dyad constructs a model by a fourfold repeat of the modeling unit which shows process-related (see units 2, 3, 4) as well as support-related (see units 1 and 2) variations.

More specifically, in unit 1 the cognitive support concerns not only the action of synthesis but also the action of analysis for the first time. Similarly, in unit 2 the cognitive support concerns synthesis and testing, while there is also an in-unit loop between analysis and synthesis. Finally, the action of analysis does not seem to decrease from unit to unit, having a rather constant contribution throughout the modeling process.

## Discussion

The aim of the present study was to highlight the ways in which collaborating students as well as a facilitator were engaged in a computer-supported modeling activity. Thus, we developed a coding scheme for analysing the process of collaborative modeling, and studied three dyads of high school students constructing shared plant growth models within *ModelsCreator*.

Developing a two-level analytic tool made possible not only to systematically reconstruct the higher-level cognitive actions through a series of well-defined lower-level operations, but also to use these reconstructed actions as insights to the activity itself. In other words, apart from performing a systematic microanalysis of each action on the underlying operational level which has already been attempted in other studies (see Stratford *et al*. 1998), we also used the action level for possibly tracing specific macro-patterns within the activity. In fact, identifying consistently both the verbal and the practical operations that are required for the performance of each modeling action and attributing them to a specific actor – either a student or the facilitator – resulted in rather useful information on both cognitive and interactional levels as already shown. Moreover, as such information do also derive from identifying specific action-based patterns within the activity, it seems that our analytic tool can actually offer an interesting insight to a computer-supported modeling activity as discussed below.

The three major modeling actions of analysis, synthesis and testing-interpreting that students performed through a wide range of modeling operations, show some differences in the part of the activity they hold, the collaboration they promote, their argumentative character and the degree of support they require. These differences may be related to the different cognitive demand that each action poses to the students.

Peers spend a significant part of the activity engaged in the action of analysis, but they do not seem to encounter serious difficulties with it. In fact, the cognitive support is either absent or limited within this action, except for the case of Dyad III. Nevertheless, it should be noted that even then, the cognitive support is much less than the one needed for the action of synthesis. Moreover, peers do not argue much about objects or properties and they do not participate symmetrically when working on them.

On the contrary, synthesis seems to be much more demanding. Peers spend most of the activity engaged in constructing meaningful links between the selected structural elements through the built-in semi-quantitative relationships. This action requires most of the facilitator's cognitive support. Significant supportive operations appear to be exclusively or mostly activated to support the action of synthesis. Furthermore, it seems that in order to cope with relational reasoning, peers need not only to be cognitively supported by the facilitator but also to be highly involved (symmetrical participation) and critical (argumentative character) as well.

Testing and interpreting holds the smallest part in the activity. The cognitive support provided within this action may seem as limited, but it is actually rather significant. In fact, testing as well as interpreting the model behaviour seems to be triggered by the facilitator through supportive operations such as explicitly requiring testing as well as checking students' understanding of the model behaviour during model run.

The modeling activity shows a pattern of repeated modeling units. Although adequate of standing alone, the facilitator-supported, three-action modeling unit is actually repeated several times until the construction of the model comes to an end. Starting with the action of analysis, the modeling unit goes on with the action of synthesis where the cognitive support mainly comes into play, and it is finally completed with the action of testing. Nevertheless, there are some quite frequent process-related variations of the modeling unit, having to do with back-and-forth shifts either between analysis and synthesis or between synthesis and testing. Finally, there have also been identified some support-related variations, resulting from the distribution of cognitive support among the three actions. It is noted that synthesis always remains the most supported.

The aforementioned features of the modeling unit may indicate a bottom-up approach to the modeling task, as peers seem to first focus on objects and properties and only later shift interest in relational reasoning to start assembling the former. Moreover, the in-unit shifts, traced between synthesis and analysis or testing and synthesis as well as the pattern of the repeated modeling units through which this bottom-up approach is attempted, do indicate that dynamic modeling has not actually to do with merely representing an already fixed mental construct, but with shaping and elaborating it step by step by interacting with the tools of the software and with each other. It is worth mentioning that according to our results this process of collaboratively shaping expressed models within a computer-based educational environment appears to need cognitive support primarily during the actions of synthesis and testing. This observation as well as the identified ways in which the two modeling actions in question appear to be supported, could probably contribute to a more effective use of dynamic modeling as an instructional approach to school science if taken into account while designing and implementing sequences of modeling-based teaching and learning.

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