Describing Construction of Knowledge through Identification of Collaboration Patterns in 3D Learning Environments

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ABSTRACT

Recent research has to a limited extent explored the nature of collaborative knowledge construction in 3D environments. In this paper we describe this issue by identifying two collaboration patterns that are manifested in the students' dialogues and actions in a particular 3D learning environment. The theoretical framework is found within socio-cultural perspectives that view learning as socially and culturally constructed and of whichartefacts are considered as inseparable from human activity. In agreement with the intellectual heritage, the collaboration patterns are identified through analyses of various extracts of dialogues and actions taken place between the students and how these extracts are operationalised by available artefacts. Interaction analysis constitutes the analytic tool.

Keywords

3D environments, collaboration patterns, joint construction of knowledge, dialog analyses.

INTRODUCTION

The aim of the paper is to describe how students construct knowledge collaboratively in 3D learning environments. We approach this issue by identifying collaboration patterns specific to such environments. Collaboration patterns are understood in terms of how students (actors) act in dialogues and in the usage of artefacts in a particular 3D learning environment. These kinds of environment "evoke a feeling of immersion, a perceptual and psychological sense of being in the digital environment presented to the sense" (McLellan 1996: 457). This means that interactivity is of vital importance; seeing as it includes the feeling of touch, sense orientation and position in space (Gorman et al. 1999). As such, 3D environments provide ways to experience and view information that are dynamic and interactive. In addition, they are proclaimed to be appropriate for model building and problem solving (McLellan 1996).

Technological advances have unquestionably been the driving force behind most designs and developments associated with 3D environments. Also, Hoffman & Vu (1997) point to the fact that there is a substantial gap between the technologies available today and the technology that is needed for realising the expectations for 3D technologies as tools for knowledge construction. Most of the educationaluses of 3D environments have been developed for professional training in technical fields such as medical education and military training (Ludvigsen & Fjuk, in press). There exist recent and limited insights into the nature of human actions in a 3D environment, and more precisely, how these activities evolve with respect to learning. To achieve a deeper insight into this area of learning, empirical analysis is necessary.

To study the area of learning or construction of knowledge (Mercer & Wegrif 1999) we thoroughly identify collaboration patterns in a particular 3D learning environment: Corpus Callosum. This environment is developed for the purpose of constructing a simulated learning environment for collaborative activities. The 15-year-old students are located geographically separated in such a way that their collaboration only takes place in networks and through real-time communication. The environment represents a planet that is threatened by an ecological disaster. The students aim to create a joint environment for task-oriented conversations and problem solving associated with various forms of disasters (flooding, drought and erosion). In this strongly visual 3D environment, all actions are operationalised by various 3D-based artefacts. The students canmanipulate different kinds of available 3D-based artefacts alone or together, and their movements and actions become visible both to themselves and the others during social interaction and oral conversation. Figure 1 illustrates a situation in which the students (represented by avatars) operationalise an action by manipulating different pieces of the aqueduct.

Figure 1: Students collaborating in Corpus Callosum solving the aqueduct task.

We analyze extracts of dialogues and actions taking place between the students, with interaction analysis as the analytic tool (Jordan & Henderson 1995), and with socio-cultural theory as the framework for discussion (Vygotsky 1978; Engeström 1987).

3D LEARNING ENVIRONMENTS: A REVIEW OF THE LITERATURE IN SCIENCE EDUCATION FOR STUDENTS

3D learning environments that are designed and organised for undergraduate students and in K-12 are very few. In the literature we find two such environments particularly interesting, and which have been the subject of research into learning situations. The content in both cases is science education.

Barab et al. (in press) focus on how learning processes in 3D learning environments evolve among 14-15 year-old youth. The environment developed is aimed at stimulating student-centred learning, in the domain of astronomy. The students are meant to collaborate "around the computer" rather than through computer networks. The students are exposed to tasks where they have to transform artefacts. This approach is coloured by their use of activity theory as an analytical tool. Barab et al. (in press) focus on two basic contradictions during their analysis of classroom activities. One is between *learning astronomy* and *building 3D models*. Another is between *teacher directed instruction* and the *emergent student directed learning*. Both contradictions lose their validity when studying how learning processes in 3D learning environments evolve. Concerning the former, the authors claim that learning and building models are parts of the same processes. When it comes to the latter, thetasks are directed towards the construction of new artefacts, which imply that the tasks have the possibilities to create learning trajectories which go beyond the distinction between instruction based or student centred learning environments (Barab et al., in press).

Roussos et al.'s (1999) focal point has been to explore 3D learning environments within the context of primary education. The designed environment is aimed at giving the students opportunities to explore the life cycle of a garden. The students should solve tasks for better understanding of various biological processes. They were meant to collaborate through computer networks. Roussos et al. (1999) embrace a constructivist, collaborative and narrative approach to learning. Their study shows some interesting results related to technical, orientation, affective, cognitive, pedagogical and collaborative aspects. Here we would like to stress two aspects related to what they have identified as pedagogy and collaboration. Concerning the former the authors underline that spreading the lessons over multiple "virtual-reality sessions" appears to be more effective than covering many topics in a single session. Concerning the latter Roussos et al. (1999) emphasize that the teachers' role mainly was to keep order and to stimulate the students to focus on the task.

THEORETICAL FRAMEWORK

Socio-cultural theories represent a distinct perspective for understanding human activity. The *relationship* between the social, collective level and how actors think, reason and act is at the core of the theories. As such, the theories are powerful for understanding and analysing the situated relationships between actors, activities and artefacts. In the study presented in this paper, these concepts are used to describe construction of knowledge through identifying collaboration patterns in 3D learning environments.

We use socio-cultural theories in a broad sense and aspects from activity theory more specifically (Vygotsky 1978; Cole 1996; Wertsch 1998; Leontiev 1978, 1983; Engeström 1987). The core argument for using these theories is the emphasis on the *social and cultural basis of human development* and the rich approach of understanding the *integrated role of artefacts*. The human development is dependent on various kinds of tools. In this respect, language has an essential role for individuals' learning and for collaboration in a learning community and between various communities (Edwards & Mercer 1987; Bowker & Star 1999; Mercer 2000). Language is thus considered as a socialmode of thinking. Moreover, how artefacts are developed and used is dependent on the object of the activity since they serve as a means to acquire, construct and retrieve different kinds of knowledge and performance (Vygotsky 1978; Leontiev 1983). Artefacts are mediators of both the *interactional* and the *operational* aspect of human actions. The former aspect is the way knowledge is constructed – individually and collaboratively. The latter aspect of the same action is mediated by the chosen tools. This implies that the artefacts become both *means for knowledge construction* and *tools*.

According to socio-cultural theories the context is essential for understanding how knowledge is constructed and for identifying how collaboration patterns evolve within learning communities. Collective aspects such as *rules of communication* and *division of work* are emphasised (Engeström 1987). These aspects mediate the students' activities in such a way that they are not isolated, but part of a *learning community*. The artefacts used, the learning community the student belongs to, and the explicitly or implicitly expressed rules and the division of work/task within that community therefore affect the individual's actions.

In the design of the learning environment, Corpus Callosum, we stressed the organisation of mutual relations between actors, actions and artefacts. In that way, this environment differs from most 3D environments because it is arranged especially for learning. Outlined from narrow studies of the students' learning activities in Corpus Callosum containing a set of various artefacts, three main situational relations were identified (Fjuk & Krange 1999). First, the actor-actor relationship makes the students able to talk through a real-time communication system. Second, the actor-object relationship makes it possible for the students to operate and manipulate artefacts by clicking, lifting and moving them, and makes premises on how they can act according to socio-material possibilities and constraints in the learningenvironment. Third, the object-object relationship concerns how manipulation of one artefact affects another artefact in the learning environment. This relation can be initiated by an actor where the result is a kind of domino effect between artefacts andit can be subscribed by how characteristics of one artefact seen in relation to another artefact can give significant information to the student. To construct joint knowledge about how to solve a task in this specific learning environment, the students have to interact and collaborate (actor-actor); they must individually or collaboratively construct knowledge about the relation between artefacts (object-object); they must individually or collaboratively manipulate certain objects and coordinate themselvesaccording to the possibilities and constraints in the learning environment (actor-object). In other words, the way in which language, dialogues and talks are supported and mediated by artefacts in 3D learning environments becomes a complex area of study,which is grounded in how the actors relate themselves to other actors, but also to the material environment they are a part of.

METHODOLOGY

The socio-cultural perspectives offer a rich set of possible units of analysis and levels of descriptions. This provides the analysts with tools that, e.g., make it possible to vary from broad descriptions of activities, to more detailed levels of actions and operations. To study learning processes in Corpus Callosum, we have analysed extracts of dialogues and the individuals' actions by using interaction analysis as an analytical tool (Jordan & Henderson 1995). Data gathered from *video recordings* of the students' activities in the virtual environment constitute the basis in this study. It is straightforward to have one of the networked clients act as a recorder, allowing the entire session in the 3D learning environment to be played back during later analysis. We used the teacher client as a recorder. The teachers' position provided an overview of all the activities in the 3D environment. This approach provides us with possibilities to focus on the temporal organisation of dialogues and actions, but also on how the technical artefacts are used to operationalise certain actions. Another important aspect is that the experiences of the students become visible and documented in the "temporal orderliness and project ability of the events they construct" (Jordan & Henderson 1995: 61). The temporal dimensions are important, but we also want to emphasize the socio-spatial aspects.By socio-spatial aspects we mean how the students oriented themselves in the environment. This becomes especially important when the students move with avatars in Corpus Callosum.

To explore how students construct knowledge in 3D learning environments by studies of how collaboration patterns evolve, three extracts of dialogues associated with the students' work with the aqueduct task were chosen. The rationale of the task was that the students had to pick up and place the aqueduct pieces in the remaining aqueduct-foundation (the H's). The aqueduct pieces have different colours, and by placing the pieces correctly, the colours formed a colour spectrum from red to blue. The task was constructed so that the students themselves found what objects to use and how to place them as well as forming the correct colour spectrum. In the empirical analysis we studied all the dialogues and actions performed by the students. The extracts are chosen to show major differences in how the students relate to each other and to the artefacts in the environment. The aqueduct task was rather complex in the sense that it required integration of other tasks as well as reasoning and negotiation.

The transcriptions of the data are conducted in the following way: When the students only talked together, we transcribed the dialogue as it unfolded. Short pauses and overlaps are indicated in the text. When students both talked and performed actions we transcribed the utterances as they unfolded, but also made an indication of what the students were doing. Such an approach creates a high level of transparency so that the reader can follow the argumentation.

EMPIRICAL ANALYSIS: CONSTRUCTION OF KNOWLEDGE BY IDENTIFYING COLLABORATION PATTERNS IN A 3D LEARNING ENVIRONMENT

Joint construction of knowledge is described by identifying two main collaboration patterns. These patterns are characterised by either sequentially or dynamically oriented activities. By sequentially oriented we indicate that the students perform the actions one after the other, and that they neither reflect upon them nor the specific character of the learning environment they are a part of. Dynamically oriented actions have a more cyclic character. When an actor tries something out, they will return to these actions and have some kind of reflection about the actions performed. This implies that the students' activities differ according to how they relate to each other, and how they manipulate and share their experiences connected to the artefacts.

It is important to note that the identification of collaboration patterns should be understood as analytical constructions, based on the data in itself, and the theoretical lenses used. We argue that there is no direct mapping from data to theory – or vice versa – a direct mapping from data to the analysis performed. Our empirical analysis is rather described as a bottom-up approach where the concepts are developed through our work with the data. These concepts arethen used as part of the analysis where the theoretical framework is used. In the next passages, we exemplify this by studies of some extracts of dialogues and related actions.

Collaboration pattern one: Sequential

There are two main subcategories of collaboration patterns according to the sequentially oriented actions. These are either based on actions characterised by hypotheses testing or on actions typified by trial and error.

Collaboration based on hypotheses testing

The dialogue that follows is selected from a setting where some students are about to start solving the aqueduct task. They have chosen to locate in the same area of the planet, while listening to the exercise.

Teacher	What shall we do then?
	(2)
Student 1	Yesterday, when I was moving around, I saw a lot of pieces around the mountains, that I didn't really know what was.
Student 2	Maybe it's the purple ones?
Student 1	Yes. Or they were a kind of long sticks with a sort of … They were grey and red.
	(2)
Student 2	Mmm
	(1)
Student 2	Some of the things I saw were similar.
Student 3	I saw them as well.
Teacher	Shall we assume that those are the right ones, and begin to collect them?
Student 3	Yes. But where shall we put them … to build those things?
Student 4	On that island?
Student 3	Yes
Student 2	Do you think that we can manage to bring them with us alone, or do you think that we have to get together two and two?
Student 4	We must try. Try alone first.
Student 2	Yes.
Student 4	Can't we?
Student 1	Shall we start walking, or …?

Student 3	We'll go around searching, and then we will see what we find.
Teacher	Yes. Okay. Great. Go on …

This extract of dialogue shows three different negotiation sequences. First (sentence 1-8) the students are negotiating about *what* kind of objects that can be used for building the aqueduct. Further, (sentences 9-11) they negotiate about *where* they shall bring the objects. Finally, (sentence 12-15) they discuss *how* they can manage to bring the objects to the island. Through these negotiation sequences the students are making several hypotheses that they will try out in their further work. The extract also gives us important information about the students' and teachers' actions during communication while one of the students asks if they shall start to walk (sentences 16-18). This indicates an interesting issue, namely that the students have not moved their avatars during the conversation. This interpretation is confirmed if we look at the video recordings of the pupils' interactions: The group does not split up until they have set out detailed hypotheses on how they are going to solve the task. Another interesting aspect is the teacher's role in the students' collaborative processes. The teacher takes the initiative related to the activities the students should perform (sentence 1), summarizes and stimulates to a turn in the students' discussion (sentence 8) and confirms that the students can start to act (sentence 18).

The analysis of this extract of dialogue indicates that the students mainly collaborate through *hypotheses testing* and *sequentially* oriented actions. The *actors* make a scenario associated with their expectation of what *artefacts* they are going to use and what *actions* they must perform in order to solve the task. During their collaboration it became evident that they were strictly loyal to the hypotheses they had made. They did not change their hypotheses for action in their meeting with the artefacts. They act as if they had total knowledge of the environment. In this way they exclude the probability of including unforeseen artefacts and different action possibilities. Further, their collaboration pattern is also characterised by a low level of division of work, and their activities are guided by collectivistic norms (Engeström 1987). This observation indicates that the students principally relate to the activities and the artefacts as representations and not as parts of their collaborative praxis.

According to the sequentially oriented collaboration the students are able to construct joint knowledge of the development of the action expiration, but they do not attain such knowledge striving to solve the task. This becomes evident because they are first able to solve the task when the teacher gives them a specific and directional hint. In other words, the sequentially oriented pattern, dominated by hypotheses testing collaboration, does not stimulate joint construction of knowledge that is relevant for solving the problem.

Collaboration based on trial and error

The conversation below is gathered from a situation where some students have worked with the aqueduct exercise for a while. One of the aqueduct pieces has already been placed at the foundation. The students move around with different aqueduct pieces. One of the students is just looking and does not participate in the dialogue that follows.

Student 1	Now I placed it somewhere. *(He has an aqueduct piece in his hands and gets rid of it up in the air.)*
Student 2	Yes, it's there. *(We can see the aqueduct piece hanging in the air.)*
Student 3	Where?
Student 2	I'm nearly standing on it. *(He fetches Student 1's aqueduct piece.)*
Student 1	No, shit.
Student 3	Now you fetched it. Yes. Then it is okay. *(He tries to place an aqueduct piece without succeeding.)*
Student 1	One of the iron things landed in the air, but when you get closer to it, it suddenly disappears.
Teacher	Can you see any differences in the various aqueduct elements?
Student 3	Maybe some of them are a little bit smaller than the others? *(They move around with objects while talking.)*
	(1)
Student 1	I would like to use that one.
Student 3	The one Thala has looks quite small.
Student 1	They look small when you hold them, I think. When you place them they look a lot bigger.
	(3)
Student 3	Yes. Thala succeeded in placing one. *(The aqueduct piece increases while it is placed on the foundation and is placed next to the piece that is already there.)*

	(1)
Student 1	Did they fit together? There are different colours on each of them. At least these two. *(The students get rid of the objects and look at the aqueduct pieces together.)*
Student 2	Yes, but then …
Student 3	Maybe it's going to be …
Student 1	It doesn't look like they really fit together. *(They are hanging around and are looking to see if the aqueduct pieces fit together.)*
Student 3	Maybe it should be rr …
Student 1	And – the one Thala placed is kind of vertical on the end.

This extract of dialogue consists of two sequences. In the first (sentences 1-7), we see that the students are discussing *where* and *how* to place the aqueduct pieces. Moreover, we observe that they struggle to put the different objects in the intended places. They are confused about what is happening and it seems obvious that they do not really understand the functionality of the system. They do not manage to share each other's experiences. It is not until the second sequence that they manage to build on each other's knowledge and their work process seems to turn into a new phase (sentences 8-19). It is important to mention that this seems to be a result of the teacher's intervention (sentence 8). The teacher gives them an essential hint that leads to a breakthrough in the collaboration.The students start to discuss the difference between the aqueduct pieces, about the size and why it varies (sentence 10). Thereafter it is the shape of the objects that is in focus: first the colours (sentences 14-18) then the construction of each element (sentence 19).

The dialogue between the students indicates that this collaboration process can be characterized as *trial and error oriented*. Unlike group one, group two starts to act prior to setting out hypotheses on how to relate to the artefacts and which activities that must be completed to solve the task. Further, it is primarily after the teacher's involvement that it is possible to register something that resembles hypotheses testing activities. In the first sequence it is quite obvious that there is no common strategy for their activities. In the second sequence (8-19) there is a slight change. The students are still acting prior to reflection, but now they are at least discussing the outcome of their actions after words. The collaboration can also be characterised as rather *sequentially* oriented, but in the opposite way of the first extract of dialogue: They act prior to sharing the information from individual experiences.

This means that the actors do not make any action expirations. They have an opposite collaboration pattern to that of the students in the first extract of dialogue. At best we see *actors* discussing the outcome of their *actions* and the use of different *artefacts* together. The primary basis for *action* is the *artefacts*. Their collaboration patterns are characterised by a high division of labour, and individualistic norms describe their activities (Engeström 1987). We maintain that the *actors* in the second group primarily relate to their *actions* and the *artefacts* in the 3D learning environment on an individual basis and that the problem solving therefore never really becomes a part of collaborative praxis.

According to the sequentially oriented collaboration the students are not able to construct joint knowledge on their own. Only after the teacher's intervention do they manage to construct such knowledge in such a way that they are able to solve the task. In other words, the sequentially oriented pattern, dominated by trial and error collaboration, does not stimulate to joint construction of knowledge that is relevant for solving the problem.

These two groups of students have in one sense distinct ways of collaboration represented by the concepts of being hypotheses testing and trial and error oriented. Nevertheless, their collaboration patterns indicate an important sign of equation, namely the sequentially divided work pattern and the lack of joint construction of knowledge related to problem solving. None of them seem to have gained consistent knowledge of how the 3D learning environment actually works. This implies that the students are not able to utilise the functionality of the 3D learning environment in a way that it is transparent for them and their problem-solving activities. The relation between actors, actions and artefactsbecomes sequential.

Collaboration pattern two: Dynamic

There is one main dynamically oriented collaboration pattern. The following conversation is between some students when they are about to start off the aqueduct task. They are moving around in the 3D learning environment.

Student 1	Okay, then I think we just pick up some pieces and place them in the H's … those iron things.
Student 2	Now I picked up an aqueduct.
Student 3	Okay, shall we get the ones which are placed around?
Student 4	Yes, the ones that look like they can conduct water.
Student 2	The aqueduct has been picked up.

Student 1	It's not … there are many …
Student 3	Shall they … do they like, live in the H's? *(Bringing in an aqueduct piece, and putting it on the foundation.)*
Student 2	I think they should lie in the H's *(Moves towards the aqueduct base.)*
	(3)
Student 1	Okay, I'll try that. I'm not sure about it.
Student 2	Okay, Student 1 is on his way with an object. *(All four of them are gathering around the aqueduct.)*
Student 1	Yes. *(He is coming towards the island with an aqueduct object.)*
Student 2	We also have to ensure that they fit smoothly into each other.
Student 3	They will do that automatically for sure.
Student 1	Like this. I placed one. I don't know how it looks. Lets see …
Student 4	That turned out well, I think.
Student 1	Oh yeah. It's beautiful.

The extract of dialogue contains two sequences. In the first sequence (sentences 1-8), the students are discussing *what* objects they shall collect, what they look like, and *where*they shall place them. They manage to develop a common platform for understanding *how* to solve the task. It is striking how the students make use of figurative descriptions to give information to the others, which utterances like "look like they can conduct water" (sentence 2) and "the H's" (sentences 3 and 4) are examples of. It is also important to note that the students in this sequence change between moving their avatars in different areas of the learning environment executing different activities and being co-located around the aqueduct. In the second sequence (sentences 9-16), their discussion becomes even more specific while they in collaboration try out different strategies for rebuilding the aqueduct and evaluate how it looks afterwards. The students are co-located around the aqueduct while talking. The students start to move around and act immediately. At the same time, they try to convince each other that the choices they are making are the correct ones. It is also worth mentioning that the teacher in this sequence does not intervene in the students' collaboration processes. Instead it seems that Student 1 takes a kind of moderator-role. He starts out by suggesting *what to do* (sentence 1), after a while he *summarises* the discussion (sentence 9) and lastly he *concludes* the outcome (sentence 16). In this way, he seems to gather the students both socially and thematically, and stimulate the progression in the problem solving process.

The students' collaboration is characterized by continuous shifts between *trial and error oriented* activities and *hypotheses testing* activities. This observation indicates a more *dynamic* collaboration pattern. This implies that the students interact in a specific manner with each other as well as with the artefacts at the "same time". This way of collaboration enables the students to reform and correct their original hypotheses during their collaboration processes, and further, the flexibility seems to be crucial for their joint construction of knowledge.

This entails that the *actors* are making a kind of action expiration together at the same time as they are inter*acting* with the *artefacts*. This makes it likely to include unforeseen artefacts and different action possibilities concurrently as these are the focus of their conversational problem solving. This group is able to optimise the learning opportunities, because they both explore the environment and reflect on their actions. They learn how to use the contingencies and constraints of the environment (Greeno 1995). This group, opposed to the two previous groups, has found a balance in their activities. Their collaboration patterns are characterised by a combination of a high and a low degree of division of work, and their norms provide opportunities for the individual actor to perform specific actions, but these actions have to be reported back to the other students, a form of collectivistic individualism (Engeström 1987). We thus claim that the *actors* relate to their *actions* and the *artefacts* in the 3D learning environment at a collective basis and that the problem solving therefore really becomes a part of their collaborative praxis.

According to their dynamically oriented collaboration the students are able to construct joint knowledge while solving the task. In opposition to the sequentially oriented patterns, the students are able to gain consistent knowledge of how the 3D learning environment actually works. This implies that the students manage to utilise the functionality of the 3D learning environment in such a way that it is transparent to them during the problem solving process. The relation between actors, actions and artefacts becomes dynamic.

CONCLUDING REMARKS AND FURTHER WORK

This paper is a contribution to understanding collaboration patterns in 3D environments and how the embedded actions evolve with respect to learning. The aim has been to identifyvarious collaboration patterns to describe collaborative knowledge construction in a specific 3D learning environment. The patterns are identified through analysis of the interrelations between actors, actions and artefacts. Interaction analysis has constituted the analytical tool.

We have identified two main collaboration patterns that are characterised as either sequentially or dynamically oriented actions. These have been discussed in the light of two subordinated aspects. These are actions characterised by hypotheses testing or trial and error. These aspects operate separately in the sequentially oriented pattern, and flexibly in the one that is dynamically oriented. The main conclusion is that the students who work sequentially oriented have problemsconstructing joint knowledge associated with problem solving, while those who work more dynamically oriented are more successful when working with the task. One important aspect of their success is their movement in different areas of the environment and how they relate these actions to each other. When talking to each other and trying out different aspects of the environment, they use the spatial affordences more creatively than the two other groups. In other words, the dynamically oriented group is able to utilise the functionality of the 3D learning environment in a way that becomes transparent to them during their problem solving process, while the former does not.

The findings in this paper point out two important issues. One is related to the design of the 3D learning environment and to what extent it is adequate in supporting and mediating different learning activities, and the other is related to the teachers' role shaping and how this is related to the students' collaborative processes. According tothe former, our analysis indicates that it is just the students whose collaboration is characterised as dynamically oriented that are able to construct joint knowledge that is relevant for problem solving. This in spite of the fact that all of them actually manage to solve the task. This implies that the design of the 3D learning environment makes is possible to solve the task - at one level - without achieving a shared understanding of the tasks and the specific functionality of the environment.

Corpus Callosum is a "closed" community, which implies that the learning activities are performed 'on demand' and synchronously amongst the students. Concerning a more demanding and complex knowledge domain the assumption that all learning activities should be operationalised in the 3D learning environment is arguably too simplistic. We know from learning research that the quality of the learning processes is highly dependent on the learners' previous knowledge, the complexity of the knowledge domain, the learners'ability to regulate the learning processes, and the situated character of knowledge acquired (Brandsford et al. 2000). These processes raise the question of complexity related to the way in which different aspects will influence the learning environment over a period of time. Moreover, Roussos et al. (1999) and Dede et al. (1996) argue for instance that spreading the lessons over multiple 3D sessions appears to be more effective than covering many topics in a single session. If we make a normative turn in argumentation, this implies that other types of learning resources should be part of a new design, and further, that the 3D learning environment should be included in a more comprehensive curriculum. The students' work could be organized in larger projects. This may support a more adequate learning trajectory for the students, simultaneously with the 3D learning environment becoming an important part of the students' learning processes.

The latter essential feature concerns how the teachers shape their role in this specific learning environment. The teacher plays an ambiguous role, also in learning activities that take place in 3D learning environments. Concerning how the students performed in Corpus Callosum, neither of the students that acted sequentially oriented were able to construct joint knowledge related to task solving. As a result, the teacher had to intervene to generate a more adequate work progress. This issue is similar to Roussos et al.'s (1999) findings where the teacher had to intervene to keep the students on the task. These are immediately problematic findings because the teacher's directional role probably never really gives the students the opportunities to form their own agenda. Moreover, neither the students nor the teacher manage to interact with artefacts in an adequate way for problem solving. This issue constitutes an interesting scope for further work.

Concerning the students that acted more dynamically oriented, they were able to use the artefacts constructively in their collaborative processes. Whether this could be explained by the more passive role of the teacher is an open question. Barab et al. (in press) claim that neither the teacher nor the pupils are directing the activities, but artefacts are. This claim is concerned with the process of learning from and with artefacts. In Corpus Callosum it is possible to give feedback to actors by help of artefacts. This feedback can in principle give procedural direction, or on the other hand, give learning possibilities for activities with a cyclic character. But without a collective effort among the students, the feedback cannot be transformed to process where knowledge is co-constructed. Since few complex concepts could be learned based on a procedure and within a short time frame and hardly in one teaching session, the design process should make dynamic and cyclic oriented actions and activities more transparent, both inside and outside a 3D environment. This direction of design can break the dichotomy between students or teacher centred learning environment, because the focus would be on the use and construction of artefacts. If so, the students and the teacher must focus on production of knowledge and new artefacts in different situations rather than how the student-teacher relationships should be regulated. This does not eliminate the problem of the teacher-student relationships, but provides insight into how to design a learning environment where the production of artefacts is in focus.

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