Supporting Problem Based Learning by a Collaborative Virtual Environment: A Cooperative Hypermedia Approach

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Abstract

Problem based learning promotes engagement in meaningful learning and cooperation among students. When applying PBL in distributed groups distance has to be bridged by means of technology. Collaborative virtual environments (CVE) can help to overcome two crucial problems of PBL, if used in a distributed learning situation: Firstly, learners have problems to understand, interact with, and tailor shared learning environments, so that they match their needs. Secondly, groups of learners have problems to construct shared knowledge in a shared learning environment. Our approach is to provide a CVE designed to support PBL. We use the metaphor of a virtual institute to organize the learning environment and to facilitate orientation in and tailoring of the CVE. In addition, we provide a graphical cooperative knowledge representation tool to help groups to construct shared knowledge in a PBL process. We use cooperative hypermedia technology to represent both shared learning spaces and shared information spaces as shared hyperdocuments.

1. Introduction

Problem-based learning (PBL) is an innovative instructional strategy. It poses meaningful, contextualized, authentic situations, and provides resources, guidance, and instruction to learners as they develop domain knowledge and problem-solving skills [10]. The principles embodied in PBL make it a learning method that promotes a number of factors known to improve learning [25]. Although the history of PBL is not long and this instruction method is still under development, PBL has been used in many settings and many professional training fields have also picked up this strategy.

Applying PBL in distributed groups leads to a number of problems. Instead of learning in the same location, groups now have to interact with new technological means. Thus, if people have to learn in a collaborative virtual environment, it is difficult for them to be aware of, interact with, construct, and customize shared learning environments that enable effective collaboration. In addition, weak communication channels and distribution of people in time and in space make it more difficult for PBL groups to carry out cognitive activities and communication activities when constructing shared knowledge in virtual environments. In this paper, we propose an approach to build a collaborative virtual environment supporting PBL. The approach uses cooperative hypermedia technology to represent both shared learning space structures and shared information structures and to provide integrated support for social orientation, social interaction, and social construction of knowledge.

The reminder of this paper is organized as follows. It begins with a brief introduction of theoretical background. From the perspective of social constructivism, two implications for the development of virtual PBL environments are identified. The main body of this paper describes our approach to design and implement a computer-supported collaborative PBL environment. After comparing with existing PBL support systems, we present our conclusions.

2. Social constructivism and its implications on the design of virtual PBL environments

The work described in this paper is based on social constructivism. In a social constructivism view, learning occurs within a social context, cognition is socially shared by members of a community, and knowledge is socially constructed and situated within activities, tools, and people in a community. According to Vygotsky [20], human psychological functions develop through participation in culturally organized activities. Psychological phenomena originate in social experience, and their constituents are socially produced artifacts. Social experience includes the manner in which people

stimulate and direct one's attention, model behavior and respond to behavior, control bodily movements, and organize the spatial relationships among individuals. Cultural artifacts include objects produced by humans (such as classroom, blackboard, books, computer, and scientific equipment) and psychological tools (such as language, algebraic symbol systems, schemes, diagrams, maps, and mechanical drawings).

PBL is consistent with the philosophical view of social constructivism. It utilizes small groups and authentic problems, and operates in a domain context. The purpose of PBL is to build up competencies in adapting to change, dealing with problems, reasoning critically, adopting a holistic approach, appreciating the other person's point of view, collaborating in groups, and self-assessment [1]. In PBL, teachers do not simply pass information to the student. Instead, they mediate student's learning through social interaction as cognitive coaches. Students themselves tackle complexity and engage in meaningful learning. They actively seek learning resources (capable peers and learning materials), and exchange and negotiate their perspectives. They collaborate to study the issues of a problem as they strive to generate viable solutions.

From the perspective of social constructivism, learning by using the PBL method can be viewed as a culturally and socially mediated activity, in which all actions are socially embedded, and all objects associated with such actions are cultural tools. Accepting this view, we argue that it is important to provide an artifact-saturated and society-aware virtual learning environment for geographically distributed people to conduct PBL activities. In the paragraphs below, we discuss two important implications for the development of a virtual PBL environment, which supports distributed groups.

2.1. Context-rich shared workspaces

Vygotsky [21, 22] proposed the concept of the "Zone of Proximal Development" (ZPD), which is defined as the difference between the level of actual development and the more advanced level of potential development using learner engagement in problem solving mediated by a tutor or capable peers. This zone can be regarded as a region of activities that individuals can navigate with the help of more capable peers. [23] states: "ZPD is not only composed of different levels of expertise of individuals, but also includes socially produced artifacts". According to Cole et al. "learners operate within constraints provided in part by the more capable participants, but they must be able to use language and other artifacts in ways that extend beyond their current understanding of them, thereby coordinating with

possible future forms of action" [5]. Furthermore, full development during the ZPD depends upon full social interaction. Social interaction takes place in an artifact-saturated medium. As Cazden [4] states: "an essential aspect of this interaction is that less capable participants can participate in forms of interaction that are beyond their competence when acting alone. It is believed that rich contexts can reflect students' interpretation of the real world and improve their knowledge being transferred in different situations". The zone of proximal development can be used to design appropriate learning environments, where the student can be provided the support (more capable participants and appropriate artifacts) for optimal learning. Brown, Collins and Duguid [3] emphasize the idea of "Cognitive Apprenticeship", which supports learning in a domain by enabling students to acquire, develop and use cognitive tools in authentic domain activity. As stated in [3], "Learning, both outside and inside classrooms, advances through collaborative social interaction and the social construction of knowledge". Lave and Wenger [9] developed the concept of "Community of Practice (CoP)" – the idea that learning is constituted through the sharing of purposeful, patterned activity. Members of a CoP are bound by shared practice, which means that they are engaged in a collective process of learning. They are fundamentally self-organized, even when external constraints influence the group. Engestroem [7] proposed a structure of human activity. As a system, human activity comprises subjects (the individual or sub-group whose agency is chosen as the point of view in the analysis), the object (the 'raw material' or 'problem space' at which the activity is directed) and desired outcomes (objects transformed into some end), instrument (classroom, equipment, language, ideas), rules (formal and informal, explicit or implicit ways of working with the object), a community (which shares the same object with the subject), and a division of labor (how actions are divided up in an activity). This framework provides a set of useful heuristics for analyzing the organization of the PBL activity. Suchman [17] argued that "action such as learning, understanding and remembering is situated. Because of the situated nature of action, communication must include an awareness of the local context and a mechanism to solve problems in understanding". These ideas of social constructivism lead to the idea of adopting a virtual institute metaphor, which provides context-rich shared workspaces for mediating social interaction. In such a virtual PBL environment, PBL groups are given spaces to explore, to socially present to other people, to seek capable peers, to organize social relation, and to arrange learning activities. They should be able to be aware of learning context, to search and access information resources (e.g., document), and to use tools

to interact with each other, to handle documents, and to perform domain-specific learning activities. Furthermore, because human activity can not be described sufficiently beforehand [17], actual learning processes are seldom executed exactly following a predefined learning plan. Especially in PBL processes, participants serve as active agents in the construction of outcomes in the social setting, in which social produced artifacts, social relations, and social activities are embedded. As a consequence, the social setting is changed and evolves during the learning processes. Therefore, it is further required for a virtual PBL environment to allow the end users to develop their own mediation system, and to become independent, self-directed learners. That is, the end users are able to construct or tailor learning contexts by reconfiguring or reorganizing workspaces, tools, documents, and their relations.

2.2. A knowledge representation tool for PBL

In the view of social constructivism, a language or a symbolic thought is a socially produced artifact, which is used by members of a specific community. "Language and symbolic thought shape the structure of mental life" [21]. As stated in [9], "knowledge and the making of knowledge are interactive, inductive, and collaborative, where multiple perspectives are represented, and where questions are valued [2]". As Wenger [24] states: "Meaning is regarded as a construction of a social unit that shares a stake in a common situation". According to [2], "a learning environment should help learners to reflect on their experience and construct new meaning".

The expected outcomes of a PBL activity are (1) acquiring knowledge and skills that can be transferred to solve similar problems at an individual level, and (2) constructing shared knowledge and promoting mutual understanding at the group level. To achieve this goal, a variety of cognitive and communication activities are performed. Guided by tutors, PBL learners identify the problem, identify learning issues, determine the learning goals, seek and exchange knowledge that is necessary to understand and solve the problem under study, generate hypotheses and solutions, reason and evaluate hypotheses and solutions, and so on. Learners contribute from multiple disciplines and learn from each other. In a virtual PBL environment, weak communication channels and distribution of people in time and in space make it more difficult for PBL groups to carry out such cognitive activities and communication activities. Using a common medium for knowledge representation may make it easier for learners to express their knowledge and to understand others' ideas. Such a common medium can be implemented as a representation tool, which serves as a PBL-specific cultural artifact for facilitating the pursuit of common understanding and construction of shared knowledge. Suthers [18] defined representation tools as artifacts with which users construct, examine, and manipulate external representations of their knowledge. Roschelle [14] suggested that "the representation tool and the collaborative learning process could be designed together for more effective learning". Because the users of a virtual learning environment may be distributed in time and in space, the jointly constructed knowledge representation should be recorded and well organized as a general accessible knowledge base. The socially constructed knowledge artifact reflects the status of consistent, conflicting, and complementary knowledge among participants. The knowledge artifact in turn stimulates individuals' cognitive activities and initiates further social interaction. As Suthers [18] pointed out, "representation tools mediate the collaborative learning discourse by providing learners with the means to express their emerging knowledge in a persistent medium, where the knowledge then becomes part of the shared context".

3. A cooperative hypermedia approach to a virtual PBL environment

This section describes our approach to develop a virtual PBL environment. Our approach consists of two parts: Firstly, we develop a knowledge representation method to structure shared information spaces for PBL. Secondly, we take a virtual institute metaphor to model shared workspaces for learning. These two kinds of spaces are represented as two interrelated hyperdocuments within the virtual learning environment.

3.1. The PBL hyperdocument

Through an analysis of PBL processes, we identify what types of information units and their relations will be handled in the PBL process. The result is meta-knowledge for expressing knowledge in PBL processes, called PBL-net schema [12]. A diagram representation of the PBL-net schema is shown in Figure 3. In this figure, the squares represent node types, while the arrows represent link types. The node types and link types that we choose are based on the various tasks that make up the PBL process. They are (1) explore the problem, (2) identify what learners know, (3) identify what learners do not know, (4) identify the goals and make action plan, (5) collect information, (6) discuss information collected, (7) apply knowledge to the problem, (8) review the process. It should be noted that in our approach the CVE does not constrain the behavior of learners and teachers within a PBL activity.

For the task of exploring the problem, the learner must define problems. Therefore we defined a 'problem' node type. A problem can be decomposed into sub-problems, using an 'is_a_sub _problem_of' link type between the main problem and its sub-parts. A 'Source' node type is defined so that background material to the problem can also be represented. An information unit with a 'source' node type can inform about an information unit with a 'problem' node type using an 'inform_about' link type. Similarly, learners will need to identify what aspects of the problem they need to learn about. Using the 'issue' node type.
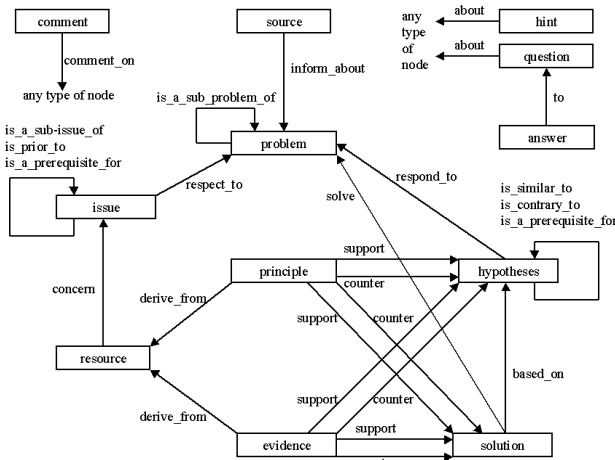

Figure 3: The PBL-net schema

When performing task (2), (3), and (4), learners declare what learning issues they know or don't know. They identify what knowledge is still missing. They decide who will be responsible for collecting information about what issues. They also have to identify the relations between learning issues. For these purposes they use link types 'is_a_prerequisite_for', 'is_a_sub_issue_of', and 'is_prior_to'. This information will be used as the basis for setting learning goals and making a learning plan.

In order to decide what information is needed and to integrate the collected information, the 'resource' node type and the 'concern' link type are defined. The 'concern' link type is used to indicate to which learning issue an information unit is related. Then, learners will debrief information and discuss by abstracting what they learned from the collected information. The 'principle' and 'evidence' node types serve to represent the acquired knowledge. Meanwhile, the 'derived_from' link type is used to indicate from which resource the knowledge about principles and evidences was derived.

In the same way, we identified other types of nodes and links according to other tasks (see Figure 3). It is important to note that information units of node type 'comment', 'hint', and 'question' can be created

whenever it is needed. Participants of a PBL activity can connect these types of information units to any type of information unit by using 'comment_on' and 'about' link types, respectively. An information unit with node type 'answer' can be created to answer a 'question' node with an 'to' link.

Based on the PBL-net schema that we have just defined, we developed a collaborative knowledge representation tool by using cooperative hypermedia technology. By means of this tool, participants of a PBL activity are able to collaboratively construct a particular knowledge representation as a hyperdocument, called as a *PBL hyperdocument*. The start node of a PBL hyperdocument is a special document node whose content contains a set of *typed nodes* and *typed links* between the typed nodes. This special document node is called as a *PBL-net node* and its content is called a *PBL-net*. Each typed node and typed link contained in a PBL-net has a "type" attribute whose value will be a node type or an link type defined in the PBL-net schema. Each typed node in a PBL-net has its content page and "statements" attribute whose value is the title of the content page of the typed node. The content page of a typed node is a *representation* of the typed node that reflects the values of the typed node. The content page of a typed node contains detailed information in the form of text, table, image, scribble, and even other *untyped nodes*. An untyped node is similar to a typed node except for its "type" attribute set to "untyped". The content page of an untyped node, in turn, contains detailed information and even other untyped nodes. Therefore, a PBL hyperdocument has two levels: PBL-net level and information level. There are some constraints in the PBL hyperdocument. For example, there is only one PBL-net node in a PBL hyperdocument (thus serving as its root object). The structure of a PBL-net has to comply with the definition of the PBL-net schema. Untyped nodes can not contain a PBL-net node. Untyped nodes can not appear in the PBL-net.

A document editor can be used to browse and edit a PBL hyperdocument jointly. First of all, to start a PBL activity, users can create a PBL-net node by using the document editor. Then they can construct their own PBL-net by creating and manipulating typed nodes or typed links on the PBL-net. To create a typed node in a PBL-net, a user should assign values to the attributes of the node: node type and node statement. The node statement serves to briefly describe the content of the node and to publish a point of view to others. While a typed node is created, its content page will be created automatically. Typed links can be created to connect two existing typed nodes while complying with the definition of the PBL-net schema. Node type specific operations can be performed on the corresponding typed nodes. For example, on nodes

with "issue" type, learners can assign values such as "I know" and "I need to know" to the corresponding attribute.

Users can navigate to the content page of a typed node. When any user of the same shared document editor navigates to the content page of the typed node, all users of the document editor will go together. That is, all users of the same document editor always work on the same document page. By using the same document editor, users can edit information units in the form of text, table, image, scribble, and untyped node. Users can create a content page for an untyped node or connect it to an existing document page. By manipulating a shared PBL hyperdocument, the users can collaboratively construct a shared knowledge representation and interact with each other through the shared knowledge representation.

3.2. The virtual institute metaphor

Our approach is based on the assumption that co-learners, who are familiar with a campus-based learning environment in the real world, will find it easier to orient and behave in a virtual learning environment showing similar characteristics. Thus, we use a virtual institute metaphor to model a virtual learning environment. The idea of the virtual institute metaphor has been described in [11]. This paper focuses on the technological approach to realize the idea.
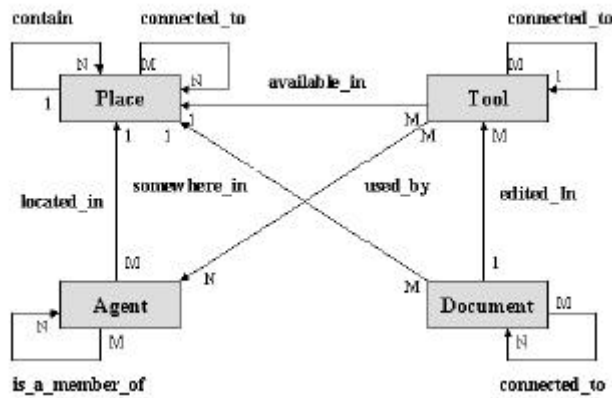

Figure 1: The E-R diagram of the virtual institute model

Our virtual institute model consists of four primary entities: *place, agent, document, and tool*. Figure 1 shows these four entities and their relations. A *place* is a computational space, within which objects can exist and social interaction can take place. There are two relations between places: the "contain" relation and the "connected_to" relation. The "contain" relation corresponds to the spatial (nested) structure within real learning environments. The "connected_to" relation provides a shortcut between two places. An *agent*

represents an actor (a learner, a tutor, or an expert) or a group. A group can consist of other agents that may be actors or other (sub-) groups. An actor or a group can be a member of more than one group. An actor can be present only in one place at a point of time and many actors can be present in the same place at the same time. A *Tool* (e.g., whiteboard, computer, bookshelf, chat board, telephone, speaker, message-box, calendar, etc) provides certain functions and is available in a place. Some tools may be connected (e.g., two phones in different places can be in a "connected" relationship). Multiple actors can use one tool and one actor can use multiple tools at the same time. A *Document* is a logical unit of information that will be handled (e.g., stored, moved, opened, or destroyed) as a whole. Documents can be connected by links. Many documents can have links to refer to the same document and a document can contain links to multiple documents. A document is located somewhere in a place, such as in a bookshelf or on a whiteboard. A document displayed on a whiteboard can be edited by means of the edit function provided by the whiteboard.

A virtual institute is represented in the virtual learning environment as a hyperdocument, called the *institute hyperdocument*. In terms of hypermedia, each place is represented as a node. Each place has attributes such as name, type, content, and owner (the latter can be an actor or a group). Possible values of the *place type* attribute are 'campus', 'administrational building', 'library', 'dormitory', 'instructional building', 'home', and 'public room' (see figure 2 for an example). The *place content* attribute refers to the set of objects located in the place.

As explained above, places are related in a spatial relationship ("contain" relation). In addition, a mechanism is needed to facilitate navigation among places. This is done via so-called *doors*. A door is represented as a hypertext link between the two nodes, which represent the corresponding places in the institute hyperdocument. A door has two states: opened or closed. There are two types of doors: concrete and virtual doors. A *concrete door* represents a "contain" relation between two places (i.e. there are doors in a building, which lead into the rooms contained in that building). A *virtual door* represents a "connected_to" relation between two places. A concrete door is implemented as a bi-directional link (facilitating navigation in both directions) and a virtual door is implemented as an uni-directional link.

The start node of an institute hyperdocument is a campus (see figure 2). The campus can contain an administrational building, a library, a dormitory, and a set of instructional buildings. In turn, a building may contain a set of rooms. Concrete doors, which form a hierarchical structure with three levels, connect the

places in a virtual institute. These levels are the institute level, the building level, and the room level. In addition, virtual doors can connect any two places in a virtual institute (thus serving as short cuts between places).

A place is visualized as a 2-D area wherein all objects in the place are visualized as icons. A visualization of a place is called a *place page*. Each concrete door will be visualized in the two places to be connected. Each virtual door is visualized only in the source place. The visualization of a door depends on (1) what types of places the door connects and (2) the status of the door. For example, if a concrete door connects a campus and an instructional building, this concrete door is visualized as an instructional building icon in the campus page, and as an exit door icon in the instructional building page. When the status (i.e. open or closed) of the door changes, the icon of the door will change correspondingly.

Actors, documents, and tools are represented in this hyperdocument as leaf nodes. A leaf node contains data whose internal structure is application dependent and is not part of the model. Navigating to such a node invokes an application according to the type of the nodes.

An actor is visualized in a place page as a picture of the actor (its human user). Navigating to an actor node leads to opening a window, in which information about the actor (such as name, learning interests, expertise, email address, telephone number, etc) is displayed.

A document contained in a place is visualized in a place page as a document icon with the title of the document. Navigating to a document node leads to opening a document editor (see explanations below).

A tool is visualized as a tool icon. There are various types of tools. Each type of tool is visualized as a distinct icon. The icon of a tool may change when the tool is used. Navigating to a tool node leads to invoking a corresponding application tool. Let's discuss some tools implemented in our prototype system. A *document editor* is an application tool that can be used to browse and edit the PBL hyperdocument, which is different from the institute hyperdocument. Three types of tool nodes can invoke document editors: whiteboard, computer, and private editor. Depending on the type of tool node the document editor might offer different capabilities. A whiteboard can be used by a group of users, who are located in the same place, while multiple users who may be located in different places can use computers. Only one user at a point in time can use a private editor. A *bookshelf* is a kind of application tool that is used to store documents. Documents contained in a bookshelf are not visible in the place page. The act of navigation to a bookshelf will open an application window, in which all titles of the documents in the bookshelf are listed in a certain order (such as alphabetical, creation time, topic, and so on). Users may open a document from this list. A

message box is a kind of application tool that is used to transfer documents between places. A *calendar* is a kind of application tool that is used to schedule actions. A *chatboard* and a *conversation tool* are text-based communication tools. A chatboard is used by multiple users located in the same place, while a conversation tool supports a private conversation between two users. An *audio tool* supports oral communication. The act of navigation to two types of tool nodes can invoke this application tool: speaker and phone tool nodes. A speaker tool is used by multiple users located in the same place, while a phone tool is used by two users who are located in different places. A *specific tool* is a general notion for application tools that support task-specific functions. Examples of such tools are document search engine and group structure definition tool. In this paper, a detailed discussion about the specific tools is omitted, because of space limitations.

So far, the primary elements of the institute hyperdocument model and their relations have been described. Various learning contexts can be constructed by different combinations of these elements. The following paragraph describes the primary operations on the institute hyperdocument.

Places, tools and documents can be added/removed/moved in an institute hyperdocument and people can navigate within an institute hyperdocument. However, some operations depend on the place type. For example, it is allowed to create instructional buildings in a campus and to create public rooms in instructional buildings. If a new place is created in the current place, the new place becomes a place contained in the current place (i.e. a nesting relationship is created). Meanwhile, a concrete door between these two places will be created. Users can also connect two existing places by creating a virtual door. Performing "open" and "close" operations can change the status of a door. Only the owner of the place has the right to open and close a door.
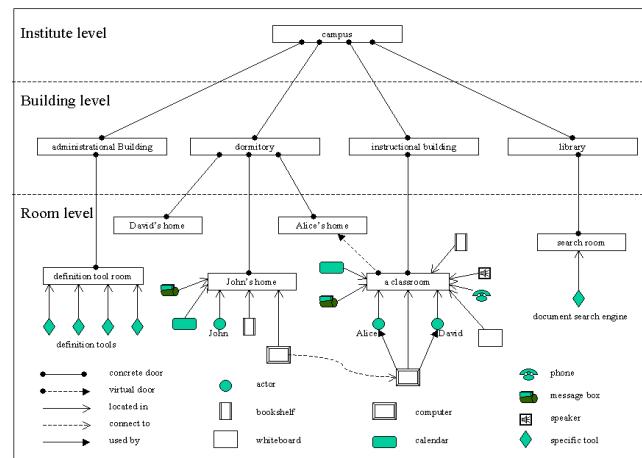
Figure 2 shows an example of a virtual institute. Three users are registered in this virtual institute and currently two of them are working in a public room (Alice and David) and are editing a document by using a computer tool. The third user (John) is working at home and is editing the same document through a computer tool that is connected to the computer tool in the public room. That is, users can collaborate both within the same place and across places.

3.3. Relation between the institute hyperdocument and PBL hyperdocuments

In a virtual institute, multiple PBL activities (courses) can take place at the same time or at different time and a user can take part in more than one PBL activity. Each PBL activity has a corresponding PBL hyperdocument. That is, multiple PBL hyperdocuments may exist in a virtual institute. The range of a PBL hyperdocument is defined as the set of documents that can be reached from the PBL-net node of the PBL hyperdocument. A document can be connected to more than one PBL hyperdocument. Because documents can be moved from one place to another place for reuse, the documents in the range of the same PBL hyperdocument may be distributed over multiple places. A place may have documents that belong to ranges of different PBL hyperdocuments. The institute hyperdocument and the PBL hyperdocuments are therefore intertwined, because a document must be somewhere in a place. In fact, the place only has an index to all documents in the place. A document itself can not be navigated in the institute hyperdocument. The act of navigation to a document icon invokes a document editor where the document will be opened. Moving a document from one place to another is just changing the document indexes present in the two places. However, separating institute hyperdocument and PBL hyperdocument makes it possible that a document can be easily retrieved in two ways. One way is to open a document in the place where the document is located. The second way is to navigate to the document by following the structure of the PBL hyperdocument. The first option relates to access via the social context, whereas the second option facilitates access to information via the shared knowledge structure.

4. Implementation and a usage scenario

The virtual PBL environment described above has been developed in the CONCERT division at GMD-IPSI. The prototype system is called CROCODILE (an abbreviation for CReative Open COoperative DIstributed Learning Environment). It is implemented in VisualWorks Smalltalk and available on Window'95, '98, NT and Solaris. It is based on COAST [16], a framework for developing groupware that provides fundamental cooperation support. COAST employs a client/server architecture. By the means of the COAST facilities, multiple users can interact with the prototype system and jointly manipulate a common set of data elements. When a user performs an operation (e.g., creating a typed node on a PBL-net) in the virtual institute, the system treats this operation as a transaction. The transaction is not only processed locally, but also propagated to other sites to keep data consistent. Finally, all clients will update their user interfaces according to the up-to-date information.

In order to demonstrate the user interface of CROCODILE and how to interact with the system, a usage scenario is described in the paragraphs below.

When a user starts the system, the login window of the system opens. The user selects the virtual institute where the scheduled PBL activity will take place. Then, the virtual institute browser window opens. As shown in Figure 5, the browser has a window title bar showing the institute's name. The upper part of the window contains the system logo, a button bar (for customizing learning contexts), and a text field (for showing the name of the current place). The lower part of the window displays the content of the place where the user is currently located.

When the user enters a virtual institute, he is located in the campus of the institute. In the window, the user can see other users currently in the campus and some building icons (administrational building, library, dormitory, and instructional building). When the user clicks on a building icon, the window content changes to show the content of the corresponding building, in which the user can see several door views. In turn, when the user clicks on an open door view, the window will show the content of the corresponding room. As illustrated in Figure 5, the user can see his picture and the pictures of other users who are currently located in the same place. If the user's cursor moves in the window content, his picture will follow the movement of the user's cursor. If two actors are talking in this place via a talk tool, the user can see an arrow with a label "talk" connected between two pictures of these actors. If the user wants more information about a user in this place, he can click on the picture of the user and a window will open with more information about the user. The user can open/close a door if the user has the right.
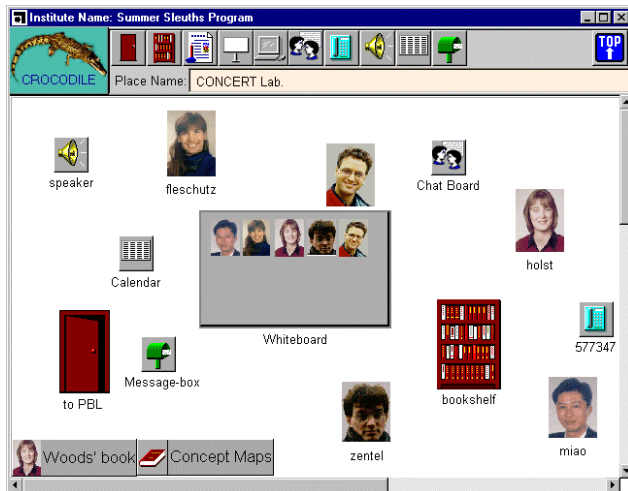
Figure 5: A public room

Figure 5 illustrates a public room as an example of a place. In this room, there is a chatboard, a speaker, a calendar, a message-box, a bookshelf, a phone, and a whiteboard. When the user selects a tool by clicking on the icon of the tool, the corresponding tool window will open. The user can look at documents stored in the bookshelf or in the message-box by clicking on the corresponding icon. The documents inside it will be listed in a pop-up window. The user can open a document by selecting it. In this room, two documents (titled as "Woods' book" and "Concept Map") are put on the floor. As indicated by document icons, a user is working on one document. The other document is still closed. In this situation, any user can open it. The user of a document can put it back to the bookshelf by dragging it and dropping it on the bookshelf icon. If the user drags the document icon and drops it on the message-box, the system will ask the user where to send this document by offering a list of places. If the user chooses one, the system will send it to message-box in the selected place.

If the user wants to share this document with others, he can drag and drop it on a whiteboard icon. A document editor associated with the whiteboard will treat this document as the currently edited document. The pictures of users displayed on the whiteboard icon indicate who are currently working on the whiteboard. When the user clicks on the icon of the whiteboard, the window of the document editor pops up on his screen. A more detailed description of the shared document editor can be obtained from [12].

By using this editor, a PBL hyperdocument can be collaboratively constructed. The user can create, delete, and modify typed nodes and links on the PBL-net. For example, to create a typed node, the user clicks on the "create node" button, selects a node type, inputs the node statement, and drops the node icon on the editing area.

The user creates links by a draw-line gesture going from the source node to the destination node. The user can navigate to the content page of a typed node by clicking on the node. Then the document browser displays the content page of the node. All users of the document editor will see the same change in their document editor window, and they can concurrently edit information on the shared content page. They continue to edit the PBL hyper-document by creating, deleting, and modifying information items in the form of text, table, image, and untyped node. During editing the shared PBL hyperdocument they can also use the chatboard tool and speaker tool for unstructured discussions.

5. Experiences

The prototype system has been tested and used in our division. Five people used the PBL approach that is supported in CROCODILE to tackle a research topic of interest in our research group. One person took the role of the tutor. This trial lasted two weeks, with on average one hour per working day. Sometimes they worked in a synchronous collaboration mode in our laboratory (because the quality of the audio tool used was not good enough), and sometimes they worked in different offices in an asynchronous collaboration mode.

The virtual institute created in this trial had seventeen places. The users were able to use the system functionality intuitively to navigate in the virtual institute, and to create new places and artifacts when they needed them. They found that the information about the local learning context was rich and easy to be understood. They used their experience from the real world to choose tools available or to create a tool, to handle documents, and to interact with each other in the virtual institute. The PBL hyperdocument contained totally about 90 nodes. The PBL net contained about 50 typed nodes and about 130 typed links, not counting the typed nodes and links removed during editing. The PBL net schema was tailored to each stage of the learning process by making different node and link types available. The typed nodes and links supported the users to construct shared knowledge corresponding to each of the stages of the PBL process. Although the users found the PBL net useful, they thought the restrictions of the computer screen width to be a difficulty. Therefore, they created separate whiteboards, which contained different sub nets as they moved through the stages of the learning process. They created one problem brainstorming net, containing mainly problem nodes, and connected them by using the link type "is_a_sub_of". The second net was more varied, in which the users focussed specifically on the issues which they needed to learn about. They used

this net to develop their learning plan and to allocate tasks. Subsequently, they used separate workspaces to collect information individually, but organized the results of investigation using a third net. Here they used the node types "resource", "evidence", "principle", "hypothesis", and "solution". Because the synchronous work was done primarily in a co-located mode, they rarely used the temporary node types such as "question", "answer", and "hint".

Overall, our experience indicates that the system enables users to easily understand the local learning context, to intuitively navigate around, interact with, and tailor the virtual institute. The PBL net supports meaningful thinking and meaningful learning, and facilitates social interaction and social construction of knowledge. The trial also raised two questions. The first question is how to handle the situation, in which a user uses a document editor in room A and wants to navigate to a document following the structure of a PBL hyperdocument. This becomes a problem when the document is currently individually used by another user in room B. For this user, the new co-author appears unexpectedly. The second question is how to provide a good overview on the PBL-net despite its continuing growth (and thus retaining an overview becomes a problem).

6. Related work

This section compares CROCODILE with other PBL support systems. Related systems are CNB [8, 13], CSILE [15], Belvedere [19], and Web-SMILE [8]. Generally speaking, these PBL support systems have been developed to support collaborative PBL between homogenous learners of high schools or of universities. These systems focus mainly on supporting science inquiry. In addition, most of them are implemented based on the Web, so that a large number of users can construct a shared knowledge representation primarily in an asynchronous collaboration mode. However, the intended users of CROCODILE are adult learners who have different backgrounds and want to improve their competence in their professional career. The problems used to drive collaborative learning are normally related to their professional work. The PBL processes carried out by using CROCODILE are normally arranged and scheduled beforehand and are performed primarily in synchronous collaboration mode. The paragraphs below discuss this in detail.

CROCODILE represents shared workspaces (for learning) as a shared institute hyperdocument that supports social-orientation and society-awareness, which is important for an effective collaboration. In addition, it enables users to construct and customize their learning environments by manipulating the shared institute hyperdocument. Such flexibility makes a learning environment into a place where learning is fostered and supported, but not dictated in a strict fashion. CROCODILE separates shared workspace and shared information space by using two types of hyperdocuments (e.g., the institute hyperdocument and the PBL hyperdocument). By this, CROCODILE supports rich forms of social interaction. Other PBL support systems are also developed by using hypertext/hypermedia, but only provide shared information spaces. Although CSILE also uses a classroom metaphor, the classrooms are used to partition the information space. In these systems, the collaborative PBL activity is mainly mediated by the shared information space. These systems support limited forms of social interaction. For example, a chatboard tool is available in CSILE and in Belvedere, but the chatboard tool can not support communication within sub-groups. All these systems did not handle the problems of social orientation and group awareness. In addition, users of these systems can not tailor their learning environments, so that the users have to perform learning activities in a predefined way.

CROCODILE enables users to jointly construct a knowledge representation for a PBL activity in the PBL hyperdocument. The PBL-net, which forms the PBL hyperdocument, is a graphical knowledge representation that consists of typed nodes and typed links. The types indicate the users' intention to create the piece of information. In addition, CROCODILE provides type specific support for typed nodes. For example, specific operations on the "issue" type nodes are provided that can help users to determine learning goals and allocate tasks. All other PBL support systems support users to categorize their ideas more or less. These systems, except for Belvedere, support users to organize their ideas by using discussion threads. Belvedere can also supports visually structured knowledge representation as a set of typed nodes and typed links. However, Belvedere supports knowledge representation only for science inquiry activity, but not for the whole PBL process. In addition, type specific support is missing in all these systems.

7. Conclusions

The theoretical basis for this work lies in social constructivism. This led us to identify two implications for the design of a CVE supporting PBL in distributed groups. Firstly, cultural and social mediation is central to PBL. Thus, shared workspaces should provide rich and dynamic cultural and social contexts to overcome the spatial and temporal gap between co-learners. Secondly, the knowledge representation method used in PBL generates and shapes cognitive activities and social interaction. Thus, a knowledge representation tool for collaborative PBL should be designed based on the cognitive activities and social activities that make up the PBL process. We developed an approach to provide a structured shared workspace and structured shared information spaces within a virtual PBL environment. This approach has five primary characteristics. Firstly, the shared workspace and shared information space are kept separate while at the same time interconnected via references. Secondly, using a set of iconic elements for the representation of the institute hyperdocument makes the shared workspace intuitively perceptible. Thirdly, by manipulating elements of the institute hyperdocument, users can construct and customize learning contexts for situated learning. Fourthly, the shared knowledge representation for PBL is visually presented. Fifthly, defining additional attributes and operations on typed nodes can support PBL-specific activities. In addition, in our institute hypermedia model, links have a status: opened or closed. It provides a flexible navigation control mechanism.

The prototype system has been tested and used in our group. Preliminary results demonstrate that the experience and skills of social interaction in the real

world can be intuitively reused in CROCODILE. The knowledge representation tool provides guidance to some extent when conducting PBL activities in CROCODILE. In the next step, we will try to address the two problems described in the last section. In addition, we will evaluate the system in real world settings. Our long-term goal is the development of an integrated virtual environment to support collaborative PBL and collaborative work in an integrated way.

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