A Design of Collaborative Learning in Terms of Supporting Emergent Division of Labor

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Abstract
In this paper, we describe an aspect of collaboration—emergent division of labor—wherein people interactively and contingently organize, maintain, and reorganize the division of labor. The emergent division of labor involves the following characteristics: (1) Emergence of division of labor, (2) Maintenance of division of labor, and (3) Reorganization of division of labor. The authors have claimed that supporting emergent division of labor is a key issue in order to make collaborative learning successful. If this claim is on the right track, then supporting emergent division of labor can be a helpful design principle for developing a Computer Supported Collaborative Learning (CSCL) system. Hence, the authors propose the following prerequisites required for a CSCL system in order to support emergent division of labor: (1) Awareness of the state of one’s own task in progress, (2) Awareness of the state of others’ tasks in progress, and (3) Awareness of others’ awareness of the state of one’s own task in progress. As examples of the CSCL system design based on this principle, the authors present two ongoing projects pertaining to development of CSCL systems: a collaborative concept mapping tool termed as “KneadingBoard” and a project-based learning management tool termed as “ProjectBoard.” KneadingBoard is intended for synchronous use, and its purpose is to help cross-pollination and the wrap-up of ideas for a small group, while “ProjectBoard” is intended for asynchronous use, and its purpose is to assist collaboration between distant students who are involved in project-based learning. Outlines of KneadingBoard and ProjectBoard are introduced in terms of the design principle based on the concept of emergent division of labor.

1. INTRODUCTION
Emergent division of labor (Kato, 2004)—an aspect of division of labor—is observed in every type of human activity. It arises from the necessity of carrying out cultural practices harmoniously. The authors believe that it is not merely essential for smooth collaboration but also significant for learning. Thus, from the viewpoint of supporting emergent division of labor, we have designed “KneadingBoard”—a collaborative concept mapping tool—and “ProjectBoard”—a project-based learning management tool.

KneadingBoard is a synchronous type of Computer Supported Collaborative Learning (CSCL) software that allows a group of learners to concurrently and collaboratively draw concept maps, i.e., graphs composed of labeled arcs and nodes. KneadingBoard enables instant sharing of these concept maps via a computer network. It derives its name from the kneading board that is used for kneading the dough for bread and pasta by comparing it with the work plane from which ideas are dreamed up.

ProjectBoard is an asynchronous type of CSCL software—a so called web application—that enables the sharing of tasks, schedules, comments, and files for a project with other members not only working on the same project but also other projects.
In this paper, the authors introduce the concept of emergent division of labor and explain its application to the design principle. Next, outlines of KneadingBoard and ProjectBoard are introduced in terms of the design principle.

2. EMERGENT DIVISION OF LABOR AS AN ARENA FOR LEARNING

2.1 Division of labor and learning

Leont’ev (1981) defined the higher functions of humans in terms of three levels: activity, action, and operation. An activity, which is composed of a set of actions, is always associated with one’s motivation; an action, which is composed of a set of operations, is not directly associated with one’s motivation but is related to it through social relationship. For example, primitive hunting is an activity that is associated with the desire for food and leather, but in a hunting team, a beater, whose role is to hound preys, never fulfills the desire by himself; it is fulfilled only in collaboration with other members of the hunting team, who ambush preys and make a kill. In this sense of activity, even if an action appears to be personal in a certain situation, by considering the context of the action and the contribution of the outcomes produced by the action, we find that it is accomplished through collaboration with others as a part of a social activity. Thus, division of labor is common in our everyday social activities.

The boundaries in the division of labor are defined by the following: institutions and rules, contingent negotiations, and sometimes by tacit consensus. Of these, the boundaries set by institutions and rules are the most apparent to others because they are clearly defined owing to simplified rules that enable people to make decisions without any confusion.

However, in practice, even when the boundaries in the division of labor are explicitly and clearly defined, people at the workplace do not always follow the rules. Instead, they are often compelled to break or renegotiate the boundary by the necessity of smooth collaboration.

Hutchins (1990), for example, illustrated some cases of division of labor by using the ethnography of team navigation of marine vessels. When a large ship is navigating in a bay, its position is measured by the following procedure: (1) A bearing time recorder along with a plotter selects appropriate landmarks from a chart and informs the bearing takers both on the starboard side and on the port side of the ship. (2) Ten seconds before the appropriate time chosen for fixed observations, the bearing time recorder gives a “standby to mark” signal. Then, the bearing taker aims at the landmark. (3) At the appropriate time, the bearing time recorder says “mark,” and the bearing taker then measures the bearing (direction with respect to the north) of the landmark and reports the result, which the bearing time recorder notes in a book called the bearing log. (4) The plotter reads the records to plot lines from the landmarks toward the measured direction on the chart so that the ship location is derived from the intersection point of the lines. Thus, the cycle from (1) to (4) is iterated regularly in order to track the ship’s progress.

This is the canonical procedure of team navigation; however, in reality, work is not always performed in this manner. Hutchins noted the following:

In ideal conditions, the nominal division of labor depicted in the preceding sections is a reasonable description of what people do. But such conditions rarely prevail. Most of the time, there are small problems being encountered and solved, small errors being committed and corrected, and little bits of interaction structure being broken and repaired. In these more usual conditions, the nominal division of labor is routinely violated. (ibid., p.209)

Hutchins showed three cases of contingent and interactive reorganization of division of labor. First, when a bearing taker at the starboard was unable to locate a designated landmark, the bearing time recorder left his position to indicate the correct landmark to him. Second, a plotter also behaved in the same manner. Third, when the plotter was summoned by the captain, a bearing time recorder took the place of the plotter and backed up his job.

The reorganization of division of labor introduces flexibility and stability into the practice system so that the system adapts to the ever-changing situations of the real world. If people strictly adhered to the rules of division of labor and were unconcerned about issues beyond the scope of their individual divisions, the division of labor would become rigid; hence, even a minor problem might turn into a catastrophe in the entire practice system.
From the viewpoint of education, such behaviors observed around the boundary of division of labor are considered to be types of concrete educational acts performed in the practical context of the workplace. Reflecting on practical collaboration in terms of education, the authors focus on the contingent social interactions of division of labor. We are convinced that such an occasion can provide a rich repertory of learning opportunities.

Educational acts that occur in the occasion include scaffolding (Wood et al., 1976), which is the process by which a more capable person guides the functioning of a novice so that the latter functions at a higher level than what he/she would have functioned at individually. Further, besides scaffolding, there are a variety of learning forms, such as a novice may mimic an expert’s behavior, novices help one another, and even a novice happens to assists or backs up an expert inversely. In any case, the authors consider it crucial that learning takes place in the context of authentic practice.

2.2 Emergent division of labor

According to the suggestion of Hutchins in the aforementioned case, some features of division of labor in good practice are listed as follows:

- Division of labor is organized interactively and contingently.
- Members often cross the boundary mutually.
- Members are always aware of the mutual state of tasks in order to coordinate their jobs.
- The boundary of the division of labor is negotiable and dynamic.
- The division of labor can be reorganized according to the requirements of the occasion.

Thus, division of labor is reorganized more or less ad lib as well as ad hoc. In this sense, the authors refer to this type of division of labor as “emergent.” However, we do not imply that some types of division labor are emergent but others are not. We suppose that in any case, the division of labor is emergent in varying degrees.

In conclusion, emergent division of labor has the following characteristics:

A) Emergence of division of labor
   One interactively negotiates the boundary of division of labor by taking into account the activities of others in their area of the division of labor.

B) Maintenance of division of labor
   One continues coordinating the division of labor through the continuous monitoring of others’ state of tasks. Since stability is accomplished through constant negotiation with ever-changing situations, maintenance involves a dynamic and aggressive process.

C) Reorganization of division of labor
   Based on the monitoring of others’ state of tasks, one begins to flexibly reorganize the division of labor, as required.

   Emergent division of labor takes place in the region where the members’ orientations overlap around the boundaries. At the same time, this is the same region where scaffolding and other forms of learning naturally emerge; therefore, it is certainly a field of collaborative learning.

   Based on the findings from the ethnomethodological interaction analysis of a scene in collaborative learning using the predecessor of KneadingBoard (described below), in which two students implicitly accomplish their division of labor, Kato et al. (2004) suggested three prerequisites for emergent division of labor:

   A) An actor has to be aware of what is happening in the peripheral area of his/her division of labor.
      This is because the actor may occasionally need to assist others when they are in trouble, since the trouble might adversely affect his/her own task.
B) Other actors that are in the peripheral area of an actor’s division of labor should be aware of what the actor is doing in his/her area. In addition, the actor has to be aware that the other actors know what he/she is doing in his/her area.

If this is not the case, when another actor suddenly breaks in on his/her task in order to assist the actor, the latter will be unable to immediately recognize the action as assistance and may perceive it as interference. In that case, even considerate assistance may ironically lead to a new confusion.

C) Skills and knowledge required to perform a task should overlap at the intersection of the division of labor.

Consider that a novice, who is quite unfamiliar with his assigned task, joins a practice group. The members around the novice will notice his impasse at the job and will attempt to help him where necessary, even though this may violate the predefined division of labor. This makeshift remedy of a practice system is possible only when the older members have already mastered the skills and knowledge that the novice is required to apply. On the contrary, sometimes the novice tentatively backs up a portion of an older member’s task by mimicking the old member’s practice. This is possible only when the novice learns the other’s task beyond his own division of labor.

When the above prerequisites are not satisfied, access to other member’s practice is limited and the emergent characteristic of division of labor is detracted. Consequently, since division of labor becomes rigid, members cannot flexibly react to the troubles that occur around the boundaries of the division of labor. From the perspective of education, the development of members’ phronesis (practical wisdom) is hindered because implicit as well as explicit learning opportunities, such as mimicking and scaffolding, are reduced.

For instance, Lave and Wenger (1991) introduced a case concerning butchers’ apprentices in a supermarket. In the case, the apprentices’ learning was restricted due to the improper layout of the workplace, in which apprentices working at the wrapping machine could not see how journeymen were cutting the meat. Accordingly, the apprentices were made to work in a manner that denied them access to activities in the arenas of mature practice.

In this context, Lave and Wenger argued that “the important point concerning learning is one of access to practice as resource for learning, rather than to instruction…. (ibid., p.85).”

2.3 Emergent division of labor as a design principle of CSCL systems

If emergent division of labor involves educationally significant characteristics, supporting and promoting emergent division of labor can be a promising principle for designing a collaborative learning environment, in particular, a CSCL system.

In order to support emergent division of labor, it is essential to have an open environment in which every participant can have easy access to mutual tasks. In particular, it is important to ensure that the participants have at least the following kinds of awareness. Meanwhile, issues related to the overlapping of skills and knowledge, mentioned previously as prerequisite “C,” are outside the scope of the design of the learning environment; this is because they are social matters concerning the design of the organization and the institution of the learning community.

A) Awareness of the state of one’s own task that is in progress
B) Awareness of the state of others’ tasks that are in progress
C) Awareness of others’ awareness of the state of one’s own task that is in progress

From among the above kinds of awareness, in normal cases, “A” does not require any special effort to accomplish. “B” is fulfilled by enabling one to mutually observe the state of others’ tasks. There are a variety of solutions for this purpose, such as remote video camera, application sharing software, remote desktop, or simply sitting side by side in a face-to-face environment. The real challenge lies with “C.” In a face-to-face situation, where people unconsciously display their orientation with eye movements, gestures, and postures, they can be aware of others’ awareness without any special effort; this awareness is inherently incorporated in everyday social behavior. In contrast, in a remote situation, awareness becomes very difficult to achieve. For example, in a collaboration using a teleconference system, one can, in theory, be aware of the activities of one’s counterpart by operating a remote camera. In reality, however, operating a remote camera is rather difficult when he/she focused is on his/her own job; further, it is also difficult to recognize from a monitor
screen whether or not his/her counterpart is aware of the state of his/her job. Thus, technological support for mutual awareness is one of the major challenges in the CSCL design.

3. DESIGN OF KNEADINGBOARD

3.1 Outline of KneadingBoard

In order to support emergent division of labor, a collaborative concept mapping tool “KneadingBoard”—is designed. Its purpose is to help cross-pollination and the wrap up of ideas for a small group.

KneadingBoard can be applied not only in a face-to-face environment in which learners in the same room directly talk to each other while watching individual screens but also in a distance environment in which distant learners communicate through speech using the telephone (or IP telephony software) or teleconference system (or messenger software). In addition, it can be applicable for asynchronous use, i.e., a learner can login to work at any time according to his/her convenience, although it is designed mainly for synchronous use.

KneadingBoard adopts a client/server model utilizing the SOAP protocol for inter-object communication. SOAP is beneficial since it provides easy passage beyond firewalls without any special settings. Being a JAVA application, it runs on any major operating system, such as Windows, Linux, and Mac OS, as long as JAVA Runtime Environment (JRE), which is distributed free of charge, is installed. With regard to Internet access, a broadband connection is highly recommended.

The main function of KneadingBoard is to draw a directed graph comprising nodes and arcs, often referred to as a “concept map” in the educational context. Nodes and arcs can be labeled and colored according to your preferences, and JPEG pictures can be dragged-and-dropped on the map either as a node or as a background. Some nodes can be combined into a group so that a group of nodes can be operated simultaneously.

Figure 1 is a screenshot of KneadingBoard after the user’s login and the choice of worksheets that the user can work with. The bigger windows that are piled on the right-hand side are worksheets and a smaller window on the left-hand side is a thumbnail of the chosen worksheets.

![Figure 1. Screenshot of KneadingBoard](image-url)
3.2 KneadingBoard and emergent division of labor

In this section, some features of KneadingBoard are described on the basis of previously mentioned awareness for supporting emergent division of labor.

A) **Awareness of the state of one’s own task that is in progress.**
The results of operations on the worksheet are immediately (in less than one second) shown on the screen, so it is easy to know the state of one’s own tasks.

B) **Awareness of the state of others’ tasks that are in progress.**
KneadingBoard provides awareness of the state of others’ tasks in the following ways:
- The results of other’s operations on the worksheet are immediately (in less than one second) shown on the screen of every logged in user.
- Mouse pointers of those who are working on the same worksheet are shown in almost real time. As shown in Figure 2, the logged in user’s mouse pointer appears as a red arrow on the worksheet and others’ pointers, which have their names attached, appear as white arrows. From the mouse pointer, one can recognize who is working on the same worksheet, and from the location and movement of the pointer in the worksheet, one can gauge the kind of task the pointer’s owner is engaged in.
- Mouse pointers of those who are working on different worksheets are also shown on the thumbnails of worksheets (Figure 3) in almost real time. Although the characters in the nodes may be rather illegible to read, one can recognize who is working on which worksheet at least from the mouse pointers, which have names attached to them. If one wants to find out more about a specific member’s state of tasks, he/she can switch from the current worksheet to the one on which that member is working by clicking on the thumbnail.
- Below the thumbnails, as shown in Figure 3, a list of the names of the current logged in users is displayed. One can recognize whether or not a certain member is at work.

![Figure 2. Multiple pointers on the screen](image)
C) Awareness of others’ awareness of the state of one’s own task that is in progress.
It is evident that users can recognize one another’s orientation through verbal communication. In addition, KneadingBoard allows a user to know if other members are aware of the state of his/her task through multiple mouse pointers. When he/she moves the mouse pointer, others may respond to the action verbally or may move their own mouse pointers in accordance with his/her action. Such a sequence of cooperative actions endorses mutual awareness.

If we refer to the usage of the mouse pointer for the functional operation of objects on the screen as the first order, and to the usage for pointing out something on the screen to others as the second order, the second order usage arises spontaneously in practice. For instance, many first-time users spontaneously begin to play chasing with others such that one approaches another’s pointer, followed by the approached pointer’s escape; the chasing pointer follows the other again, and so forth. This experience is helpful to bring users to the second order usage, that is, awareness of other’s awareness of the state of his/her task. Kato et al. (2004) reported a case of using multiple pointers in which a user moved her mouse pointer in order to indicate a specific area of the worksheet to her partner.

What plays an important role for the second order usage of a mouse pointer is not the function that the pointer can operate an object on the screen but the movement or gesture of the pointer. Therefore, it is desirable to share the movement of a mouse pointer mutually in real time. However, the SOAP protocol over the Internet cannot afford it. At present, for the KneadingBoard clients, the coordinates of pointer locations are retrieved from a KneadingBoard server every 30 milliseconds at most; however, this frequency is insufficient to continuously show the pointer’s movement. Therefore, inbetweening of a mouse pointer by linear interpolation between sparse coordinates is applied to achieve virtually smooth movement of the pointer.

Figure 3. Thumbnail window of screenshots and of logged in users
4. DESIGN OF PROJECTBOARD

4.1 Outline of ProjectBoard

Most of the Japanese universities provide their students with Internet-ready computer facilities. In parallel, the number of students who are in possession of a personal computer with broadband access to the Internet has risen markedly in recent years. Consequently, using a personal computer and the Internet has become a common practice for students in higher education. Under these circumstances, the authors designed ProjectBoard in order to allow learners to access information anytime and from anywhere through the Internet using a personal computer.

ProjectBoard is a web application, developed with Java STRUTS, for supporting project-based learning in higher education. The server is Apache Tomcat 5.0.28 and the database is MySQL. Clients can employ any major web browser on any operating system. It is a type of groupware for sharing information on statuses of the projects, mainly through four views: ProjectHome, To-Do List, Schedule, and FileBox.

ProjectHome (Figure 4) is used to allocate tasks to individuals. The tasks are to be marked manually as “not yet started,” “in progress,” or “completed.” It also provides an overview of the average stage of progress for all registered tasks and the overall progress of the project.

To-Do List (Figure 5) allows users to separately register their tasks, and a bunch of tasks can be combined into a category so that they structure the entire project. The degree of the progress of a task is indicated by a scale from 0 to 100%.

Schedule (Figure 6) is a simplified Gantt chart, in which the start and complete dates and deadlines of tasks are displayed in a table formula.

FileBox (Figure 8) is a file archiver for common use. Its function includes version management, and the locking of files in order to prevent simultaneous updating by other members.

4.2 ProjectBoard and Emergent Division of Labor

A) Visualizing Tasks and Roles in a Project

In order to allow learners to assess and reorganize the division of labor, it is necessary to make them aware of how each one of them has worked so far and how he/she is going to work from this point onward.

ProjectBoard was designed to visualize what tasks are to be undertaken and which learner in the project is responsible for each task. ProjectHome (Figure 4) indicates the manner in which learners organize their division of labor and the progress of their respective tasks. The learners can monitor the progress of their task as well as those of others. The statuses of the tasks are labeled into “not yet started,” “in progress,” and “completed.” With regard to the progress of the tasks mentioned ahead, the average of the progress of all tasks is used to deduce the overall progress of the project.

In addition, the learners have access to all the files pertaining to the assigned task(s) from ProjectHome, and they can make announcements or send a notice to all members using a memo space provided below the window.
B) Visualizing the Structure and the Status of Tasks in Project-based Learning

Even if a member is engaged in his/her own individual tasks, it is important to provide the members with a general overview of the entire project so that they can make sense of the others’ tasks as well. Therefore, it is important to provide a structure of the project in order to facilitate emergent division of labor—this enables the learners to assess whether or not the tasks in the project are appropriately organized and progressing well.

In ProjectBoard, To-Do List (Figure 5) provides the learners with the structure of the project in the form of a tree view.

In addition, the learners can recognize the progress of each task from percentages ranging from 0% to 100%: a 100% progress implies the completion of a task. Learners can also confirm the schedule for each task only when its deadline is registered in the Schedule list (Figure 6). A red box circumscribing a task serves as an alert for the learners who are behind schedule. The progress ratio and the alert indicators are designed to attract the learner’s attention toward others’ tasks as well as his/her own so that he/she might cross the boundaries of the division of labor, which provides good learning opportunities.
C) Enabling Manipulation and Mutual Editing of Tasks

In order to ensure flexibility in reorganizing the division of labor, each member of the project is equally authorized to edit the status of the tasks (Figure 7). This is because there is generally no power hierarchy in a student community. This point differentiates it from the prevailing business-oriented project management tools.

In addition, FileBox is provided for file storage pertaining to the task. It is commonly available for all the members (Figure 8). All the members are allowed to edit and update the files. Therefore, in order to prevent version confusion, the files can be locked for exclusive editing. The list in FileBox includes file name, explanation of the file, file size, version number, date and time of recent update, name of the updater, and a short note on the updated file. Thus, this function is that of version management, which allows all the uploaded files to be reserved.
D) Enabling the Monitoring of Task_statuses of Other Projects in the Same Class
Due to the necessity of scaffolding and mimicking in the expansive arena of learning, the learners are allowed to access the statuses of the other projects as well their own project. The page “Project Select” (Figure 9) shows all the project(s) performed by a class, which include not only the learner’s project(s) but also those of the others’. The learner can view any project, although he/she cannot edit To-Do Schedule Lists and FileBoxes of other projects. By way of observing other projects, the learners are expected to enhance their exploration of more effective learning strategies in project-based learning. In an attempt to arouse the learners’ motivation by studying other projects, Project Select indicates the overall degree of progress of the entire project.

5. CONCLUSIONS AND FUTURE WORK
The concept of emergent division of labor and its educational significance was described. The authors claimed a possibility of applying this concept to the methodology of designing a CSCL system. This was illustrated by the design of KneadingBoard—a collaborative concept mapping tool and ProjectBoard—a project-based learning support tool.
In their future works, in order to refine the methodology based on this concept, the authors will revise the tools according to the findings obtained from educational institutions utilizing these tools. Specifically, we will scrutinize the manner in which KneadingBoard is employed in both face-to-face and distance environments by using interaction analysis in order to compare the differences in the manner of organizing division of labor, and evaluate ProjectBoard in actual classes in the universities to see how students manage their project with this tool.

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