Facilitating Group Learning in Science Laboratory Courses Using Handheld Devices

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Abstract: The laboratory course is an inferential curriculum designed to foster science inquiry ability in science education. However, in the universities of Taiwan, laboratory courses often last only a limited time and explore only a single topic of inquiry. Students' individual ideas and experiences are not well represented in the group inquiry process. Therefore, this study attempts to provide an organizing tool on PDAs to help student groups regulate their inquiry processes and engage in reflective inquiry activities.By gathering data from 56 students (17 groups) participating in the laboratory course, this study utilizes handheld devices as an observational tool for peer interactions in collaborative inquiry activities. A total of 360 minutes of activity log was analyzed for details of peer interaction in order to understand how handheld devices can influence group regulation when students are provided with group regulation functions on PDAs. Students demonstrated six main types of interaction when formulating group inquiry plans via PDAs. This study makes distinction between four patterns of cooperative PDA use. Such distinction could assist teachers and system designers in facilitating group activities by avoiding unfavorable interaction patterns. The results show that unperceived conflicts concealed in individual devices impede peer interaction. This finding suggests that designers of learning environments should consider the importance of reinforcement mechanisms applied in Mobile Computer Supported Collaborative Learning (MCSCL) to maintain shared understanding.

Keywords: Laboratory courses, group regulation, handheld devices, peer interaction analysis

1. Introduction

The laboratory course follows an inferential curriculum designed to foster science inquiry ability in science education (Hinrichsen & Jarrett, 1999; Hollingworth & McLoughlin, 2001). Students in laboratory courses learn how to pursue scientific knowledge through inquiry and experience the process of constructing such knowledge (Edelson, Gordin, & Pea, 1999). Within the inquiry process, students formulate testable hypotheses, measure variables, and design experiments. However, in current practice, the design and implementation of laboratory courses is based on an instructional rather than hands-on approach (Mayer 2004; Kirschner, Sweller , & Clark, 2006), i.e., students complete experiments step by step according to the textbook or an instructional manual provided by the teacher. Such an approach deprives students of the opportunity to experiencethe reflective inquiry process and to learn how to acquire knowledge through that inquiry process in laboratory courses and settings.

Collaborative inquiry has recently come to be considered an effective mode of reflective scientific inquiry. Students can actively develop problem solving and knowledge construction activities during peer discussion and interaction (Blumenfeld, Marx, Soloway, & Krajcik, 1996; Littleton & Hakkinen, 1999). Peer discussion and interaction can facilitate social construction of knowledge (Jonassen, 1994) that cannot easily be attained through individual inquiry learning. However, laboratory courses often last onlya limited amount of time and explore only a single inquiry topic. For example, laboratorycourses in the universities of Taiwan consist only of weekly 3-hour classes covering a single topic. Students' individual ideas and experiences are not well represented in the group inquiry process due to time limitations. Thus, students may fail to get the opportunity to exchange ideas and experiences with peers. Furthermore, previous studies have confirmed that students still have difficulty formulating testable hypotheses, designing conclusive experiments, and compiling compatible data (Manlove, Lazonder, & De Jong, 2006). In order to achieve effective reflective scientific inquiry, student groups need regulative support in collaboratively forming inquiry strategies. Therefore, it is necessary for laboratory courses to provide an organizing tool to help student groups regulate their inquiry processes and conduct reflective inquiry activities.

Prior to this study, researchers (Manlove, Lazonder, & De Jong, 2006) had developed some regulative learning tools on handhelds designed to help students with collaborative development of inquiry strategies; handhelds had become increasingly affordable in classrooms over the course of recent years (Roschelle, 2003; Zurita & Nussbaum, 2004; Liu et al., 2006; Fry & Hin, 2006; Liu & Kao, 2007), and increased student participation and collaboration in classrooms had been experimentally facilitated by means of handheld devices. However, although students could use handhelds as regulative tools in their pursuit of knowledge, they had difficulty generating a complete group experience in the limited time available. They could not easily exchange experiences with peers due to lack of individual inquiry experience. Therefore, this study designed an inquiry learning activity which integrated in-class discussion of inquiry planning using PDAs with pre-class regulation of inquiry plaming. Students could organize individual exploration plans on the web to build individual inquiry experience in advance. At the laboratory, handhelds were adopted as a group regulation tool to help students organize and discuss their group inquiry plans based on their individual inquiry plans. This study attempts to bridge the gap between individual and collaborative construction of knowledge in order to promote efficiency and effectiveness in science laboratory courses.

This study attempts to understand how handheld devices can influence group regulation when students are provided with group regulation functions on PDAs. Recent research methodologies in Computer Supported Collaborative Learning (CSCL) have put significant emphasis on the micro analysis of peer interaction, through which improvement of learning may take place (Stahl, Koschmann, & Suthers, 2006). This study not only takes into consideration the performance gain resulting from technologies but also attempts to uncover the reason why the technology improves the interactions that lead to meaningful learning (Liu et al, in press). Accordingly, this study uses micro analysis to explore the interaction demonstrated by student groups using the group regulation functions of PDAs. Furthermore, to provide a comprehensive understanding of how the PDAs and regulation functions influence group inquiry achievement in laboratory courses, this study also analyzes the relationship between group inquiry achievement and interaction patterns as revealed by micro analysis. By gathering and analyzing the system usage logs of 56 college students in a laboratory course in National Central University, this study attempts to answer the following research questions based on peer interaction analysis:

- How do the students in a group interact with each other through PDAs with group regulation functions when using pre-regulated inquiry plans to form a group plan?
- What kind of peer interaction patterns can be observed when students develop regulative strategies using PDAs that have group regulation functions?
- How do the peer interaction patterns facilitated by the PDAs influence group inquiry achievement?

2. Group inquiry planning via handhelds

The laboratory course involved in this study included a pre-class inquiry regulation activity and an in-class collaborative inquiry regulation activity. The pre-class inquiry activity required students to build individual inquiry plans based on a given science topic. Students were thereby able to learn the procedure and objectives of an inquiry activity. In the in-class inquiry regulation activity, students were required to work with their partners to generate a group plan based on the pre-generated plans. This study developed a pre-class inquiry regulation tool on the web. Using this tool, students could make an inquiry plan. An inquiry plan consists of six main items: (1) purposes of the inquiry, (2) related theories of the inquiry, (3) instruments, (4) hypothesis, (5) measurement variables, and (6) procedures.

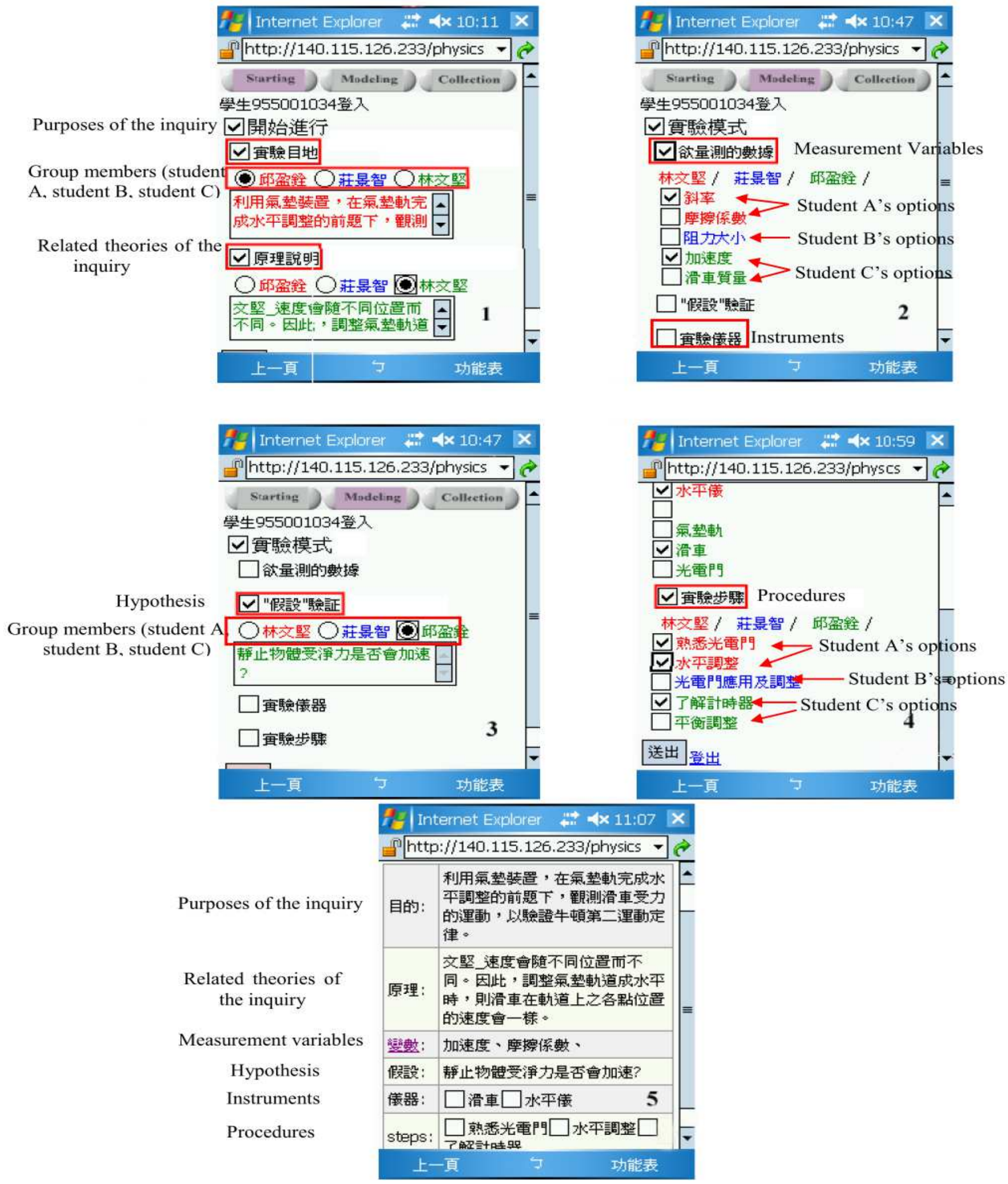

Figure 1. The regulative tool for group inquiry planning on PDAs

In the laboratory, the teacher would outline the purposes of inquiry, and then student groups would start to regulate their group inquiry plan, which would contain the same six main items found in the individual inquiry plans. In order to formulate testable hypotheses and design conclusive experiments, students were asked to collaboratively revise and discuss the individual inquiry plans they had generated on the course website to reach a unified group plan. The handhelds were used as an organizing tool to combine students' individual plans into a group inquiry plan. Using the PDAs, students could review their own inquiry plans and compare them with those developed by their partners while deciding on a unified group plan. An application on the PDAs could generate a summary of the group inquiry plan based on the decisions the students made in class. Students could then proceed to the inquiry activity and gather data based on the unified group plan. This whole process is interactive, because students were able to modify the group plan during the inquiry if necessary. After collecting all the data necessitated by the group inquiry plan, students would discuss and develop a final report according to the inquiry plan summary generated by the PDAs. Finally, the teacher would evaluate the inquiry achievement of the student groups based on the final reports.

This study develops a regulative tool for group inquiry planning on PDAs intended to support group members in comparing, reviewing, and generating unified inquiry plans (Fig. 1). The regulation tool enables students to use PDAs to refer to each others' pre-designed individual inquiry plans. During class activities, the individual inquiry plans students made before class became options that all students could choose from when selecting the six main items for their group inquiry plans. Students could review and check the provided options for the main items on the PDAs. In order to generate a summary of an inquiry, firstly students needed to decide on the purposes and related theories of the inquiry. Individuals' plans regarding the above main items were shown as options in different colors (Step 1 in fig. 1). Students could distinguish between and compare the different options provided by the group members by color. Secondly, students needed to decide which of the measurement variables proposed by group members should be included in the group inquiry plan Students were able to do this using the PDAs by checking boxes next to the variables (Step 2 in fig. 1). Thirdly, students needed to select a hypothesis for the inquiry from among the hypotheses proposed by the group members (Step 3 in fig. 1). Fourthly, students needed to decide on an executable procedure for the inquiry from the list of procedures proposed by the group members (Step 4 in fig. 1). After students had finished the group regulation activities, the tool would generate a summary of their inquiry plan on the PDAs (Step 5 in fig. 1). These interactions were recorded on the PDAs along with details of the peer interactions that took place during the group regulation and inquiry activity. Students' activities on the PDAs were archived for later analysis of peer interaction so that the effect of the PDAs' group regulation tool on learning experience in laboratory courses could be confirmed.

3. Method

The primary purpose of this study is to explore the effects of handheld devices with the above mentioned regulation functions by analyzing the peer interactions involved in collaborative inquiry activities. The participants were 56 freshman students enrolled in a physics laboratory course at National Central University (Taiwan). Students were divided into 17 groups, whose size ranged from three to four students. This study analyzes student interactions over the course of two 3-hour sessions of a weekly laboratory class, during which they performed experiments focused on Newton's second law of motion and the law of conservation of angular momentum. Students were able to make their inquiry plans on the course website provided by the study. During the laboratory class, students modified their inquiry plans, referred to options presented in other group members' inquiry plans, and regulated a unified group plan using the PDAs provided by this study. All of the students' interactions were recorded by the PDAs while the students regulated their group inquiry plan. After the class, the teacher evaluated the inquiry reports.

Figure 2 shows the collaborative inquiry behavior found in two threads as recorded by the PDAs. For instance, if student 1 (s1) checks item 1, this behavior is denoted as s1 (1). Likewise, if student 1 checks the second option of item 3, this is denoted as s1 (3_2). All regulation activities of individuals, such as modifying options, choosing options presented by other group members, and reviewing/comparing options provided by group members, were logged in the PDAs. The activity log helps demonstrate the students' regulation behaviors and development of regulative strategies as aided by PDA-based tools. This study analyzes peer interactions to determine what peer interaction patterns students can engage in through PDAs and to confirm the influence of the regulation functions provided by PDAs on the effectiveness of inquiry activities.

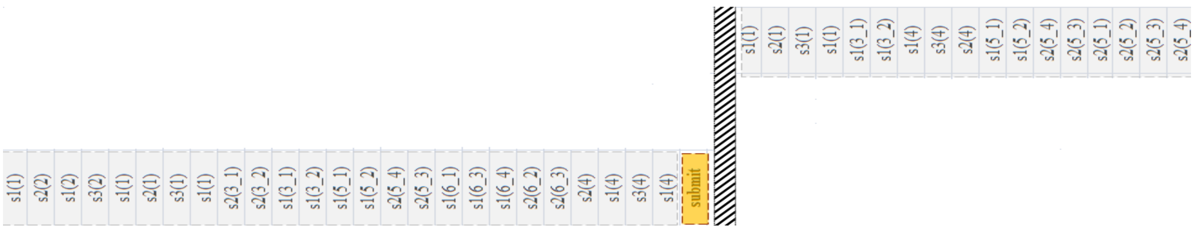

Figure 2. The activity log

As students performed collaborative regulation activities in the laboratory, data were collected and recorded by the PDAs. This study analyzes a total of 360 minutes of activity log. All analyses of peer interactions were performed by two independent researchers (coders). The analyses included the identification of peer interaction activities, e.g. comparison, conflict, and resolution, as well as the classification of peer interaction patterns. The inter-coder reliability (agreement) for each analysis was at least 85%, indicating that the analysis is sufficiently reliable. Researchers resolved disagreements in analysis and categorization through discussion.

4. Results and discussion

The results of the analysis are categorized to address the following questions. (1) What types of peer interaction can PDAs facilitate in order to help students to regulate their plans? (2) What general patterns of peer interactions can be observed in students using PDAs? (3) How do the general patterns of peer interaction affect student achievement in the context of the inquiry activities required by the laboratory course?

Peer interactions through PDAs

The activity logs were analyzed in detail to explore the peer interactions that occur during group regulation activity. Upon analysis of the activity log, six main types of interaction were identified within the group regulation activities. These types are as follows:

- Comparison: Students often compared their own individual inquiry plans with those of others by switching the options of some items. In general, they performed such activities in a short period of time in order to understand the inquiry plans of others.
- Perceived conflict (change of options): Such interaction occurred when one student chose a different option from that which was chosen by another group member. This behavior indicates that the student has noticed a difference of opinion between himself/herself and others regarding the group inquiry plan. For instance, if student A chooses the hypothesis proposed by student B as the hypothesis of the group inquiry plan, student C might modify the group inquiry plan by choosing another hypothesis proposed by himself/herself, creating a perceived conflict between student A and student C.
- Perceived agreement: Such an interaction occurs when a student reviews the group plan and agrees on the group inquiry plan as proposed by others.
- Resolution of conflict: While regulating a group plan, student A might switch to the option that student B chose after detecting the conflict between B and himself/herself (perceived conflict) regarding that item in the plan. Students A and B would then have reached a resolution regarding this item.
- Unperceived conflict: The PDAs are personal devices that allow individuals to modify inquiry plans. There generally exists a time lag between personal modification of the application server and acknowledgment of the modification on other members' PDAs. For example, one student might modify the group inquiry plan with his/her PDA and thus cause a conflict with the group plan proposed by others. If other students cannot detect the conflict before this inquiry plan is sent off to others, this is unperceived conflict. Since the inquiry plans were concealed in the PDAs, other students sometimes could not detect the conflicts between themselves regarding the inquiry plan.

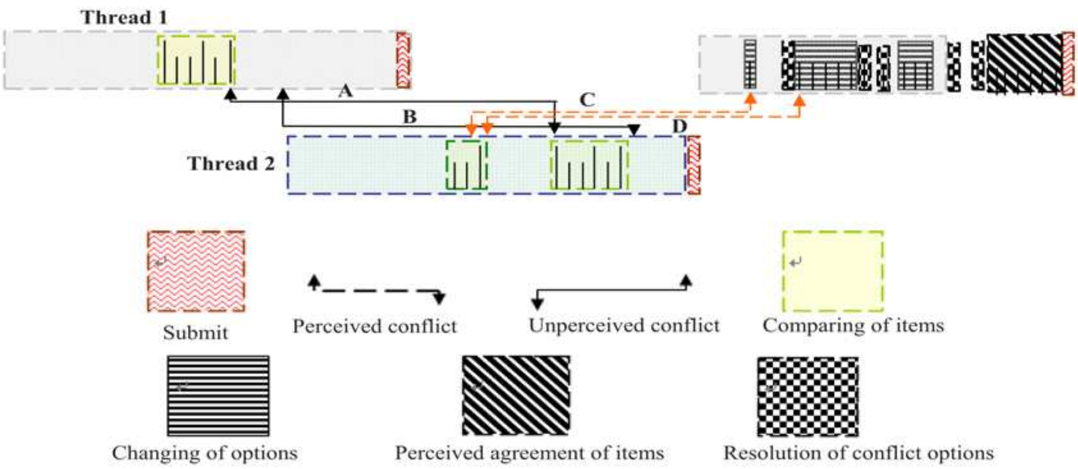

Figure 3. Group dynamic chart

In order to depict peer interaction explicitly, this study codifies and represents students' interactions based on the aforementioned peer interaction events in a group dynamic chart (Fig. 3). Each bar in a row represents a thread of student regulation activity in the PDA. Each dotted arrow from one thread to another in the chart denotes a perceived conflict. For example, Fig. 3 shows two threads that proceeded concurrently after the student in thread 2 submitted his plan. The other student in thread 1 checked a different option for an item and noticed the conflict between his inquiry plan and those of others (e.g.: line C and line D). Therefore, there is a dotted arrow between the two threads to represent the perceived conflict. In addition, each thick arrow between threads in the chart denotes an unperceived conflict. For instance, the arrow between threads 1 and 2 in the first chart of Fig. 3 reveals that a student had not noticed another student's inquiry plan and did not perceive the difference between that plan and his/her own (e.g.: line A and line B), because the student in thread 1 had not submitted his/her plan. A rectangle with vertical lines represents a student comparing his/her plan with those of others. Each long vertical line indicates a student checking his/her own plan, while a short line indicates him/her checking the plans of others. A rectangle with a horizontal line shadow denotes conflict and modification. A rectangle with a diagonal line shadow denotes conflict resolution. Perceived agreement is indicated by a rectangle with a dotted shadow. The group dynamic chart of each group was analyzed to determine what interaction patterns occurred during the collaborative inquiry activities.

Analysis of the group dynamic chart reflects the frequency of different peer interaction activities. Table 1 lists the frequency of each type of peer interaction. Table 1 reveals that PDAs helped students obtain a global view of each individual's inquiry plan. Students frequently performed comparison activities using the PDAs. In total, students performed such comparisons on 152 items in the different individual inquiry plans. In addition, the PDAs also helped students to express agreement with their group members. While comparing different options, students showed perceived agreement in 94 items of the group inquiry plans. In addition, students detected perceived conflicts in 75 items and chose 169 options which differed from those chosen by their peers. Of the changes of option selection in the group inquiry plans, 65 options were ultimately determined to be consistent among group members. Thus, there were still many conflicts that remained unresolved. Interestingly, unperceived conflicts occurred with high frequency. The log generated by the PDAs shows that there were conflicts between members over 79 items. This indicates that conflicts among students are often concealed when PDAs are used to mediate the formation of group plans. When using such a mechanism, students still have difficulties solving conflicts when attempting to create a unified group plan.

Table 1. Frequency of peer interaction in collaborative inquiry regulation activity

Interaction types	**Frequency**
Comparing of items	152 items
Perceived agreement	94 item
Perceived conflict (changing of options)	75 item (169 options)
Resolution of conflict	65 (options)
Unperceived conflict	79 items

Peer interaction patterns through PDAs

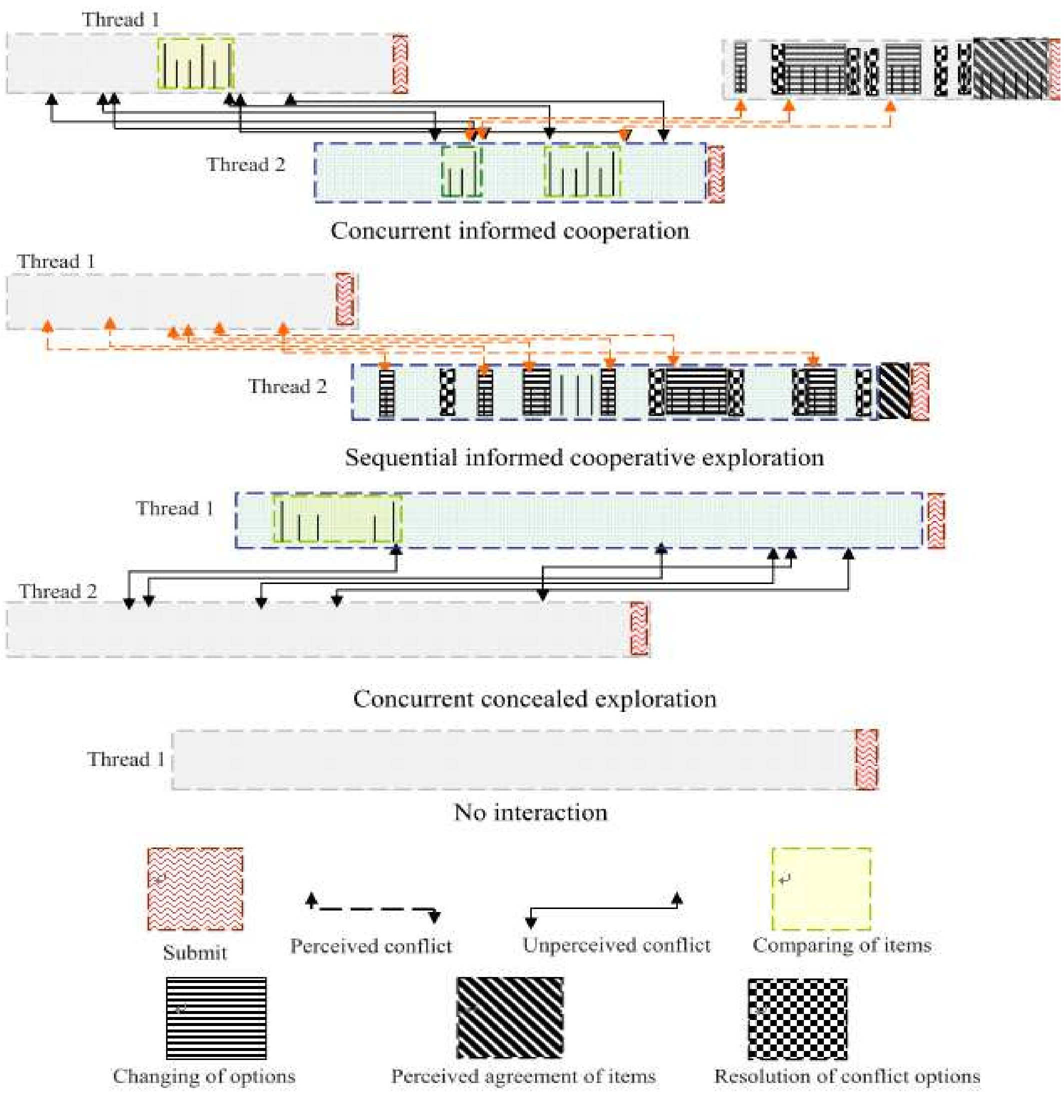

Figure 4. The group dynamic chart of four peer interaction patterns

Analysis of the group dynamic charts identifies four distinct interaction patterns (Fig. 4) occurring during the collaborative inquiry activities observed in this study. These patterns are as follows:

- *Concurrent informed cooperation*: This pattern takes the form of two concurrent threads and occurs when students begin by working independently and then jointly revise each other's plans to form the final plan. At the beginning of this pattern of interaction, individuals do not inform each other of the work they are doing, but instead each organizes a group plan individually. This behavior allows for frequent occurrences of unperceived conflicts at the beginning due to the concurrent nature of the participation. At the later stage of the pattern, students revise their group plans based on the individuals' results. Perceived conflicts are detected and resolved only at this stage. Therefore, the main characteristic of this pattern is the initially independent organization of group plans, upon which students then jointly base further revision of their group plan.

- *Sequential informed cooperation:* This interaction pattern occurs when students organize their plans sequentially, i.e., one student initiates a new thread and modifies the group plan, and then another student further revises the group plan based on these modifications. Unlike concurrent informed cooperation, this pattern only allows for perceived conflicts. There are no unperceived conflicts between the two threads.
- *Concurrent concealed cooperation:* Students following this pattern organize their plans concurrently and independently. They do not notice the difference between their own inquiry plans and those of others. The conflicts between their inquiry plans are concealed, and thus many unperceived conflicts occur in this pattern. Consequently, students who exhibited this pattern did not demonstrate any conflict resolution.
- *No interaction:* This pattern occurs when students do not interact with each other to make their group plans.

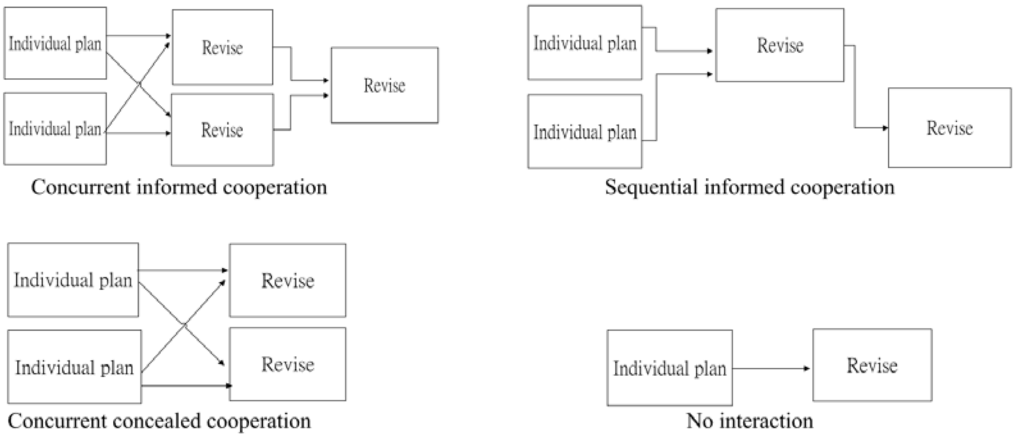

Figure 5. Peer cooperation patterns of the four interaction patterns

The four interaction patterns defined by this study demonstrate how students work together to organize their group plans using PDAs. Figure 5 presents the four peer cooperation patterns in a comprehensive manner. In concurrent informed cooperation, students generated group plans based on all individual inquiry plans and then revised the plan collaboratively. Students exhibiting sequential informed cooperation generated a group inquiry plan and then each revised the plan one after another. Less productively, using the concurrent concealed cooperation pattern, some students generated group plans based only on their individual plans without any cooperation. Even more disconcertingly, some students did not interact with each other at all when formatting their group plans, in accordance with the no interaction pattern.

This study categorizes the interaction patterns of each group based on the group dynamic charts. The distribution of interaction patterns is represented in Table 2. Only five groups demonstrated concurrent informed cooperation while thirteen groups exhibited the pattern of sequential informed cooperation. Surprisingly, there were ten groups working in the pattern of concurrent concealed cooperation and six groups working in the no interaction pattern; that is, students in these groups worked independently even when the regulation tools of the PDAs were provided to facilitate group regulation of plans.

Table 2. Group achievement distribution among different interaction patterns and interaction behaviors mediated by PDAs

Group	Type of cooperation	Planning time	Score	Compariso n of items	Change of options	Unperceive d conflict	Perceived agreement of items	Resolution of conflict options	Resolution ratio
6	Concurrent informed cooperation	00:22:43	A+	5	7	4	6	3	43%
1		00:25:36	A	5	5	6	9	4	80%
20		00:21:49	A	12	9	6	6	5	56%
2		00:30:29	A-	6	4	5	10	3	75%
18		01:45:50	A-	7	10	6	6	5	50%
23	Sequential informed cooperation	00:20:40	A+	5	9	0	4	4	44%
3		00:21:23	A-	5	5	0	6	2	40%
22		00:22:40	A-	5	13	0	3	5	38%
5		00:23:52	A-	0	13	0	3	5	38%
7		00:15:31	B+	0	8	0	8	3	38%
29		00:14:04	B+	6	11	0	2	5	45%
31		00:13:26	B+	0	15	0	1	7	47%
11		00:18:39	B+	0	10	0	5	3	30%
12		00:16:28	B+	5	11	0	6	3	27%
14		00:13:41	B+	5	10	0	3	2	20%
16		00:16:32	B+	0	9	0	7	0	0%
19		00:17:48	B	6	6	0	9	2	33%
21		00:12:17	B	5	14	0	0	5	36%

4	Concurrent concealed cooperation	00:08:23	B	5	0	5	0	0	0%
8		00:09:26	B	4	0	5	0	0	0%
9		00:10:35	B	5	0	5	0	0	0%
10		00:12:46	B	5	0	6	0	0	0%
13		00:09:28	B	5	0	5	0	0	0%
24		00:09:01	B	6	0	5	0	0	0%
26		00:08:16	B	11	0	5	0	0	0%
27		00:09:59	B	5	0	5	0	0	0%
28		00:09:25	B	5	0	6	0	0	0%
30		00:11:38	B	7	0	5	0	0	0%
15	No interaction	00:05:50	B	0	0	0	0	0	0%
32		00:04:36	B	5	0	0	0	0	0%
17		00:01:41	B-	6	0	0	0	0	0%
34		00:05:49	B-	0	0	0	0	0	0%
25		00:04:05	B-	0	0	0	0	0	0%
33		00:03:59	B-	6	0	0	0	0	0%

The interplay between interaction patterns and inquiry achievement

Student interaction and interaction patterns were analyzed to reveal how different patterns of interaction affect inquiry achievement in the laboratory course. This study thus analyzes group interaction patterns: group performance as it relates to the five interaction types, time used to regulate group plans, and the ratio of conflict resolution to demonstrate how the students used PDAs in the laboratory classes to affect their achievement in the course. Because the PDAs were used to help students resolve conflicts and create shared inquiry plans, this study measures the resolution ratio within each group by formula (1). The formula can also be used to determine how different peer interaction patterns affect group inquiry achievement.

$$\text{Resolution ratio} = \frac{\text{Total number of resolution of options by group members}}{\text{Total number of changing of options}} \quad (1)$$

Table 2 shows the analysis of inquiry achievement and planning time in terms of peer interaction patterns and interaction activities. Students displayed different characteristics with regard to interaction patterns and interaction activities. Obviously, students required more planning time in concurrent informed cooperation and sequential informed cooperation than in concurrent concealed cooperation, because the former two patterns require time for students to understand each other's opinions and to resolve conflicts. The average planning time for concurrent informed cooperative exploration and sequential informed cooperative exploration were 41 and 17 minutes respectively. In contrast, the average planning time of concurrent concealed cooperation was only 10 minutes.

Furthermore, groups whose interactions were classifiable as the sequential informed cooperation pattern showed a higher frequency of perceived conflicts than those demonstrating concurrent informed cooperation. Groups exhibiting concurrent informed cooperation also had a higher conflict resolution ratio than that of groups following the sequential informed cooperation pattern, probably because each student following the concurrent informed cooperation pattern, after independently revising the group plan, had acquired richer experience organizing group plans and thus was better prepared to establish agreement in later activity. Conversely, student groups adhering to the pattern of sequential informed cooperation, despite ultimately demonstrating high perceived agreement, were unable to achieve conflict resolution ratios as high as those of concurrent informed cooperation groups, possibly because students following other students' work when revising group plans lack personal experience in group plan development.

In the teacher's evaluation of the final inquiry reports, the concurrent informed cooperation groups obtained the highest overall scores (ranging from A- to A+) of all interaction patterns. The groups using sequential informed cooperation achieved the second highest scores (ranging from B to A+). Table 2 shows that planning time and resolution ratio may each play an important role in affecting group inquiry performance. When using the patterns of concurrent informed cooperation and sequential informed cooperation, students spent more time planning and achieved higher conflict resolution ratios.

These patterns were defined on the basis of the various types of interaction engaged in by the groups. By comparing the differences and similarities of the 34 groups, some basic rules to categorize their interaction patterns could by developed:

- Concurrent informed cooperative exploration: Students spend a great deal of time planning their inquiry (41 minutes on average). Groups following this pattern demonstrated a high conflict resolution ratio (on average 61%) and high perceived agreement (7.4 on average). Student groups following this pattern achieved the highest overall scores (ranging from A- to A+) in the teacher's evaluation of the inquiry reports.
- Sequential informed cooperative exploration: Groups following this pattern showed a high frequency of perceived conflicts (10.3 on average). Students could perceive conflicts among themselves but did not reach a high conflict resolution ratio. Student groups following this pattern achieved the second highest overall scores (ranging from B to A+) in the teacher's evaluation of the inquiry reports.
- Concurrent concealed exploration: Students work independently with only limited interaction. Some conflicts go unperceived. Neither conflict nor agreement is perceived by students. Student groups following this pattern achieved the second lowest overall scores (B) in the teacher's evaluation of the inquiry reports.
- No interaction: There is no perceived conflict nor resolution. Student groups following this pattern achieved the lowest overall scores (ranging from B- to B) in the teacher's evaluation of the inquiry reports.

5. Conclusions

Because of the difficulties students encounter with inquiry in laboratory courses, this study attempts to provide students with regulative tools on PDAs to aid in regulating and interacting with peers. Analysis of student interaction through PDAs found five main types of peer interaction, i.e.comparison, perceived conflict, perceived agreement, conflict resolution, and unperceived conflict, when student cooperation is mediated by PDAs. The benefits of using PDAs in cooperative planning activities include the ability of PDAs to provide each student with free access to the artifacts (individual inquiry plans) produced by every group member and thus to negotiate directly with peers regarding those artifacts in order to produce group work. The four main interaction types (comparison, perceived conflict, perceived agreement, and conflict resolution) that students demonstrated through PDAs are important negotiation activities. This result reflects the effect PDAs have in facilitating the negotiation of group work.

However, unperceived conflicts were frequently observed because of the client-server nature of PDA software. The implementation of the regulation tools on the PDAs in this study did not enforce simultaneous synchronization among the PDAs of group members. In other words, the changes to the group plan made by one member were not immediately displayed on the PDAs of other members. Students were able to obtain the most recent state of the group work only by reloading after all members had submitted their latest group plans. This facet of the design resulted in the frequent occurrence of unperceived conflicts.Unperceived conflicts may lessen the ability of students to share their learning experiences with each other.Technological devices, PDAs in the case of this study, can record and reflect students' current ideas and states, but unperceived conflicts may still be concealed in the individual devices. Further investigation into the possibility of an effective status awareness mechanism to synchronize the work of individuals in PDAs may be required to alleviate the problem of unperceived conflict. For example, the reinforcement mechanism applied in MCSCL to maintain shared understanding among group members may be applied to establish mutual understanding.

This study also identifies four interaction patterns that are indicative of the different styles of interaction afforded by PDAs. The four interaction patterns are: concurrent informed cooperation, sequential informed cooperation, concurrent concealed cooperation, and no interaction. Teachers and system designers should take note of the advantages and disadvantages of using PDAs in facilitating group activities and use this information to avoid unfavorable interaction patterns such as concurrent concealed cooperation. Different interaction patterns may have different advantages and disadvantages. For instance, although students in groups using sequential informed cooperation could perceive the current status of members, they still could not easily resolve their conflicts. Such difficulties may result from the lack of prior experience in learning. On the other hand, student groups using concurrent informed cooperation could easily resolve conflicts but had problems with time constraints and some unperceived conflicts. However, the best way to help students efficiently negotiate and avoid unperceived conflicts still requires further investigation.

Students engaging in different interaction patterns showed different levels of inquiry achievement. Generally, the amount of time used to regulate group plans and the ratio of conflict resolution seems to affect student achievement significantly. A high conflict resolution ratio helps students achieve high scores in the final inquiry report. The study results confirm the importance of shared agreement in negotiation activities. This result is consistent with the current principle of collaborative learning, which states that students have to express and discuss divergent ideas in order to construct and share knowledge collaboratively (Puntambekar, 2006). Therefore, educators using PDAs in classrooms and the designers of groupware on PDAs should not only support students in expressing personal ideas but should also build a mechanism or a protocol, such as the display of different personal ideas as in this study or the MCSCL mechanism (Zurita & Nussbaum, 2004), to mediate the negotiation process and help establish shared agreement.

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