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The Patterns of Collaboration in hands-on and Computer-Automated Labs

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ABSTRACT

Learning in the laboratory is a discovery process where students learn by physically manipulating the laboratory apparatus and collaborating with team members. However, the development of new information technology makes new types of labs available but also presents a paradox. Advocates and detractors of different lab modalities can be found. A full-text review of sixty articles indicates that group collaboration might be very important to explain the debate over different labs but often ignored. In this research, I focus on identifying behavioral patterns of small groups in performing laboratory activities. Founded on activity theory, I proposed a conceptual model describing the relationship among group collaboration patterns, the openness of the lab instruction, the closeness of the group, the interactivity of the lab interface, and students' learning performance. Hypotheses are developed and research methodologies are introduced to test these hypotheses. This research has a broader implication for theories, education, and the industry.

Keywords

Group collaboration patterns, hands-on labs, simulated labs, remote labs

INTRODUCTION

The increasing use of automation presents a quandary to institutions of higher learning. On the one hand, automation technologies can multiply the effects of pedagogy by allowing professors to teach large numbers of students who are geographically dispersed. But, on the other hand, a reliance on automation will change the entire learning environment and may remove the unexpected situations associated with traditional learning that actually help students understand the fundamentals of the experiments. This dilemma is especially prominent in laboratory-based learning.

Researchers have convincingly argued that information technology has dramatically changed the laboratory education landscape (2002). The nature and practice of laboratories have been changed by two new technology-intensive automations: simulated labs (Mcateer, Neil, Barr, Brown, Draper and Henderson, 1996) and remote labs (Canfora, Daponte and Rapuano, 2004). They are seen by some as educational enablers (Ertugrul, 1998; Striegel, 2001) and by others as educational inhibitors (Dewhurst, Macleod and Norris, 2000; Dibiase, 2000).

Advocates of computer-automated labs argue that simulated and remote labs can work as effectively as, or even better than, traditional hands-on labs (Shin, Yoon, Lee and Lee, 2002). Hands-on labs are seen as too costly while simulated/remote labs extend the accessibility and improve the flexibility of the conventional labs (Cooper, 2000; Hutzel, 2002).

Detractors of simulated/remote labs argue that only practical labs can provide the students with real data and "unexpected clashes": the disparity between theory and practical experiments that are essential for students to understand the role of experiments (Magin and Kanapathipillai, 2000). Simulated and remote labs are incapable of providing the physical interaction with the laboratory apparatus, which will in turn impair student learning and performance (Grant, 1995).

RESEARCH QUESTIONS

What might explain the unresolved debate over the effectiveness of different laboratory technologies in education? Johnson, Johnson and Smith (2000) suggest that there is an inextricable link between the knower and the known and "all education is a social process" that occurs "through interpersonal interaction within a cooperative context".

Information technology changed not only the way that the laboratory material can be presented but also transformed the way that students collaborate and communicate in laboratory activities (Otero, 2001). Having the student conduct the labs together in a physical space and perform the labs remotely present different implications for student learning in areas such as face-to-face interaction propensity, individual accountability, and media used for group communication (Hollingshead, McGrath and O' Connor, 1993). Questions are raised, will remote labs encourage or discourage group interactions? How does a group communicate differently in different labs? Will the group have more or less face-to-face interaction? Will the group tend to have more independent work or more group work? Does group collaboration in different labs follow certain patterns?

These questions will be addressed through the identification of patterns of small group behavior in the execution of laboratory experiments. Moreover, this study will explore the relationship between group collaboration patterns and student learning performance. In particular:

R1: What are the patterns of group collaboration in hands-on, simulated and remote labs?

R2: Will different patterns of group collaboration lead to different learning performances?

R3: What factors might influence the patterns of group collaboration in different labs?

The concept of pattern was first developed and documented by Christopher Alexander in the architecture field (Alexander, Ishikawa, Silverstein, Jacobson, Fiksdahl-King and Angel, 1977) and later applied to domains such as HCI (human computer interaction) (Schummer, Borchers, Thomas and Zdun, 2004), education (Hogan, Nastasi and Pressley, 1999), and business (Perlow, Gittell and Katz, 2004). Patterns can be segmented into activity patterns and design patterns. Based on the work of Martin and Sommerville (2004), I focus on activity patterns in this study and define the patterns of group collaboration in the labs by mapping the linkages among different phases in a laboratory activity, identifying the regularities in group organization of work and the interaction among participants.

SIGNIFICANCE OF THE STUDY

Initially, this topic may seem very specific, but I believe that it is timely and has broad significance. For example, by closely analyzing patterns, the findings may be generalizable across other domains. First, the collaboration patterns discussed in this research have important implications for remote education. In remote education, group collaboration is a heavily discussed topic. However, it is still not clear how remote work gets done in groups and how to organize remote work effectively. Therefore, research on patterns of group collaboration may afford educators a clearer understanding of remote collaboration which, in turn, may lead to better remote education.

Second, the issues addressed in this research will contribute to the design of remote technology. For example, the control of a remote laboratory is very much like the control of a remote robot. And the control of a remote lab in a classroom is very similar to the control of remote manufacturing capabilities. Thus, the practices learned in remote labs then can also apply to other related fields.

Third, the results of this study will help to build a general foundation to the design literature. It will further develop the peer group support system evaluation in a distributed collaborative environment. In addition, the "what-if' mechanism provided by our pattern research will advance the development of virtual collaboration in industry. And, should this research discover that group collaboration patterns impact learning performance, findings may also be generalized to the organizational context. The implications are significant: this research could contribute to the improvement of group performance in virtual collaboration. Outsourcing and globalization make virtual collaboration all the more relevant. The key question is how to make virtual collaboration successful

The following content is organized into five sections: (1) a brief review of the current status of the group collaboration literature; (2) the development of a theoretical foundation; (3) the proposal and development of hypotheses; (4) a discussion of research methodologies relevant to the identification of group collaboration patterns and an explanation of experimental design, operational definitions, and measures for all the variables: and (5) a general discussion and presentation of implications for future research.

LITERATURE REVIEW

I conducted a full-text literature review of 60 articles selected from three electronic databases (IEEE, ACM and ScienceDirect) and six primary educational journals (articles are listed in the appendix) for a systematic understanding of the laboratory collaboration literature. The search was based on educational goals proposed by the Accreditation Board for Engineering and Technology (ABET) (2005) and other taxonomies of lab work (Herron, 1971; McComas, 1997; Newby, 2002; Schwab, 1964). As such, I developed a four-category inventory for the educational goals of laboratory learning (table

I). Using this framework, the 60 papers were analyzed and evaluated. The literatures on hands-on, simulated and remote labs are summarized in Figure 1. Conceptual learning and professional skills are two dimensions emphasized by all the papers. Design skills and social skills are two dimensions varied a lot.

Lab Goals	Description	Goals from ABET
Concept learning	Extent to which the laboratory activities help students understand key concepts taught in the classroom and solve problems the concepts.	Illustrate concept/principles
Design skills	Extent to which the laboratory activities increases the student's ability to solve open-ended problems through the design and construction of new artifacts or processes.	Ability to design and investigate
		Understand the nature of science (scientific mind)
Social skills	Extent to which students learn how to productively perform engineering-related activities in groups.	Social skills and other productive team behaviors (communication, team interaction and problem solving, leadership)
Professional skills	Extent to which students become familiar with the technical skills they will be expected to have when practicing in the profession	Technical/procedure skills
		Introduce students to the world of scientist and engineers in practice
		Application of knowledge to practice

Table I. Educational Goals for Laboratory Learning

Research suggests that design is an essential element of the nature of the laboratories and critical to exposing students to open-ended situations, improving their ability to create and investigate(Hegarty, 1978). I found that more than half the hands-on laboratory papers recognized the importance of design skills, however, this is not the case for simulated labs and remote labs. Nine out of twenty studies on simulated labs and one paper on remote labs established design skills as an educational goal, which suggests that advocates of remote laboratories think these labs are effective for teaching concepts, not design (see figure 1)

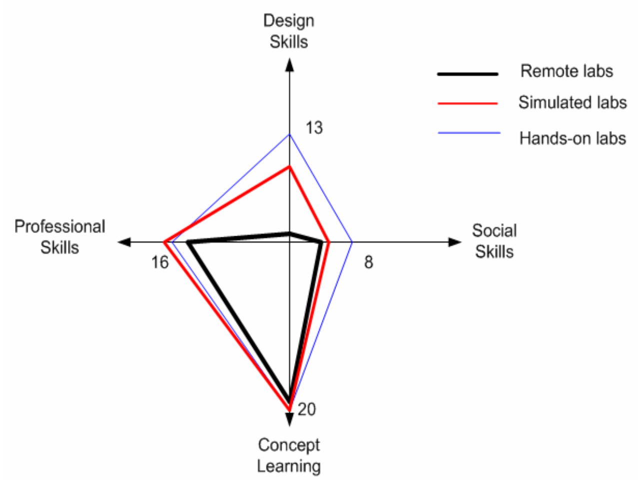

Figure 1. Educational goals of hands-on/simulated/remote labs

Social skills ranked lowest. Although social skills are explicitly identified by ABET and other researchers (Edward, 2002; Magin, 1982) as one of the important goals for engineering education, they are not discussed as often as the other educational goals. The literature review suggests that social skills form the weakest dimension in laboratory learning. Four out of twenty papers on remote labs and five out of twenty papers on simulated labs in my review discussed or mentioned the importance of social skills. There is an urgent need for research on social activities in computer-automated labs.

THEORETICAL FOUNDATION

Activity Theory (AT) has become an important theoretical approach in both HCI (Human-Computer-Interaction) and CSCW (computer-supported cooperative work) communities. Kaptelinin, Nardi and Macaulay (1999) and Nadi (1996) said that AT is not a predictive theory, but instead a powerful tool to analyze complex phenomena.

Activity is modeled as a three-level hierarchical system: activity, action, and operation (Kuutti and Arvonen, 1992). An activity is a collective phenomenon which involves interactions between the subjects, the tool, and the objects. Actions are functional processes of an activity and will be realized by operations. Fundamentally, "activity theory proposes a strong notion of mediation—all human experience is shaped by the tools and sign systems we use" (Nardi, 1996). Building on that, Engeström (1998) extended AT and applied AT to HCI research, which will be also useful in modeling group collaborative activities in the labs for the following reasons.

First, group collaboration in different labs is a learning process which requires social interactions with the team members and other people, and an exchange with the physical environment via the laboratory apparatus. This is consistent with the essential ideas implied by activity theory. Second, the unit of analysis in activity theory is a dynamics system that involves three levels of an activity. Each lab can be viewed as an integrative and dynamic system addressing group collaborations and their interactions with the lab environment, by which the concept of three hierarchical levels of an activity (activity, action and operation) can be applied to group collaboration in the labs and provide a basis for identifying group collaboration patterns.

As a result, AT presents a solid basis for structuring the relationships among all the components of a pattern and identifying different group collaboration patterns. In the following section, I will use the framework provided by AT to analyze group collaborative activities in different laboratory contexts. The effects of social context (the group) and the physical context (the lab) of group collaboration will be addressed.

HYPOTHESES DEVELOPMENT

Founded on activity theory, a conceptual model discussing the relationship between group collaboration patterns, group characteristics, the feature of lab interface and students' learning performance is proposed (see figure 2). Cooke and Szumal (1994) developed an inventory of three group interaction styles: constructive, passive, and aggressive. They reported that the variations in group interaction styles may lead to different performances on problem-solving, and such results are found to be also applicable in a virtual context (Potter, Cooke and Balthazard, 2000). On a more general level, Hara, Solomon, Kim and Sonnenwald (2003) studied scientific collaboration between a group of scientists and defined it as a continuum, ranging from complementary collaboration to integrative collaboration. In addition, the context of the group collaboration is found to be very important to explain the variations of different group collaboration. For example, Perlow et al. (2004) emphasized the national and organizational context where the patterns of group interaction emerged. Martin and Sommerville (2004) viewed patterns of cooperative interaction as the link between ethnomethodology and design, arguing that the patterns generated from previous studies could be useful resources for design in new settings. Therefore, I hypothesize that hands-on labs, simulated labs and remote labs provide different environments for group collaboration and therefore, present different implications for group collaboration patterns:

H1: Group collaboration patterns are different in hands-on, simulated and remote labs

Groups typically have a variety of collaboration patterns, but those patterns may have a different impact on group performance. For example, for the three interaction styles proposed by Cooke and Szumal (1994), constructive interaction style is found to be the best in both the traditional and the virtual context. Similarly, Beal, Cohen, Burke and McLendon (2003)) also found that among four progressively increasing patterns of work flow, namely, pooled, sequential, reciprocal, and intensive, the intensive work flow has the strongest positive influence on cohesion-performance relationship. Recently, Amponsah (2003) found that patterns of communication have a significant impact on the effectiveness of learning and important implications for interaction design. Therefore, I expect that different group collaboration patterns will have different influence on group learning performance:

H2: Different group collaboration patterns are associated with different group learning performance.

In the following section, I will look at the interactions between group characteristic, lab interface characteristics and group collaboration patterns more specifically. Proximity theory suggests that with greater distance among people, the cost for getting together will increase and therefore more effort will be required to collaborate with each other. Thus, in a simulated or remote lab where the students are not required to meet with each other, group members who live far away will predictably be more likely to use mediated communication rather than face-to-face interaction, assuming that students always try to minimize their effort to get the work done (Sander, 1999). Social network theory (White, 2004), on the other hand, suggests that the relationship distance among group members may also affect the communication and coordination mechanism selected by the group. For example, team members with stronger ties are predicted to have more intense interaction and more collective work. Using the closeness of the group to represent both the physical distance and relationship distance among the group members, I hypothesize that:

H3: The closeness of the group will significantly influence the pattern of group collaboration

Although the effectiveness of different labs, especially simulated labs and remote labs cannot be determined by technology per se, the capability of the technology may vary a lot in its ability to engage the students and motivate interesting discussions among the students. Computer-automated labs can have different interfaces, such as audio, desktop, 3D graphics HMD (head-mounted displays) etc, which vary a lot in interactivity. As suggested by Rafaeli and Sudweeks (1997), interactivity is often used as an indicator to evaluate the quality and capability of computer-automated labs. Multimedia learning theory also suggests that students will have more behavioral interactions given a more interactive interface (Barker, 2002; Mayer, 2001). Thus, I hypothesize that:

H4: The level of interactivity of the labs will significantly influence the pattern of group collaboration

In addition to the technology used in the labs, the nature of the lab itself may lead to different group collaboration. Building on the categorization developed by Schwab (1964), Herron (1971) and Hegarty (1978), McComas (1997) proposed a four-level taxonomy to describe lab openness depending on whether the lab problem, the procedures to do the lab, and the answers of the problems are predetermined or not. A high level of inquiry/openness gives the students increased responsibility and ownership over the laboratory activity while at the same time promotes more involvement and discussions with the group/TA/instructor (Domin, 1999). Thus, I expect:

H5: The openness of the lab will significantly influence the pattern of group collaboration

Taking all previous discussions into account, the groundwork to build a mediated model of group learning performance is laid. Specifically, as group closeness, the interactivity of the lab interface, and the openness of the lab vary, so do the group collaboration patterns, and ultimately, group learning performance.

H6: Group collaboration patterns will mediate the relationship between the interactivity of the lab, the openness of the lab, the closeness of the group, and the group's learning performance in the lab.

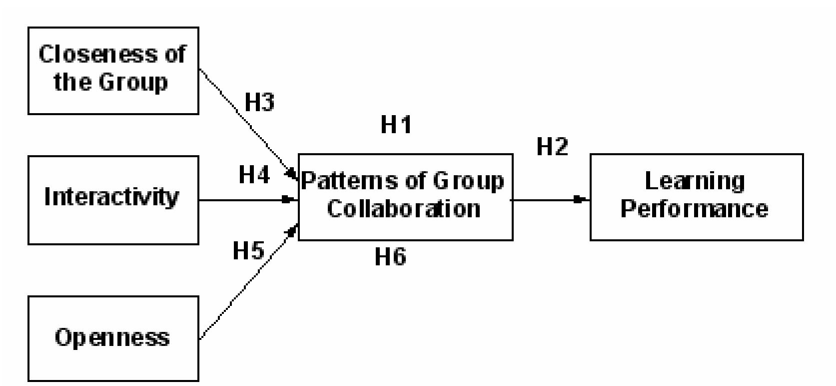

Figure 2. Conceptual Model

METHODOLOGY

The methodology consists of two steps: In the frist part, the results from two preliminary studies, an observation study and an interview study, will be presented. Building on that, methodology designed for future work will be discussed in the next section in which a large-scale survey will be distributed to collect the data and the methodology to analyze the data and test the hypotheses will be presented.

Preliminary studies

A systematic approach is developed to investigate more on the dynamics of collaboration in computer-automated labs. First, two small-sample studies—observational study and interview study—are conducted as preliminary studies. Based on the results from preliminary studies, a large-scale survey will be developed. In addition, a small laboratory experiment will be planned to have a deep understanding of the problems presented by the survey.

Observational study

Observations were made in an Engineering Design lab at a large school of engineering in the Northeast. The observer sat in on two classes of the same course with 24 students in each class. A final design project was observed, in which students were asked to design, test, and build a beam experiment. This final project lasted four weeks; each class met once a week for three hours. The observer sat through the whole class and made detailed observation notes for each class. The observer focused on how students interact with the apparatus, their peers, TAs and instructors.

The analysis of observational study suggests three main points. First, as a mandatory part of the laboratory assignment, students in real labs have intensive interactions with the apparatus. Second, students' learning can be augmented in different ways which include the interactions with the teacher, the teaching assistant, and other students. In particular, I found peer interactions happened quite a lot and it might be the most effective way to promote learning. Third, more learning interactions seemed to imply more collective work. These two activities tend to be interdependent. Also, a hybrid working style seemed to be preferred. Most of the teams have both individual work and collective work.

Interview study

In addition, nine semi-structured interviews were conducted. It was a summer-session course in the Mechanical Engineering department. Three teams were in that course and each team consisted of three students. Ten questions were designed to reflect on group collaboration in hands-on labs as well as remote labs. Approximately, ten minutes were spent on each interview.

The results suggest that group collaboration strategies may vary a lot under different laboratory settings. Comparatively, three collaboration strategies are adopted in the three teams: hot collaboration, warm collaboration and cold collaboration. Team I was in favor of face-to-face interaction and a collective work style. There was a large overlap in personal relationships as well as study relationships among the team members because of which they were comfortable with real-time, face-to-face meetings to organize their collaborations and finish the assignment. The collaboration dynamics in this team are indicated in Figure 3.

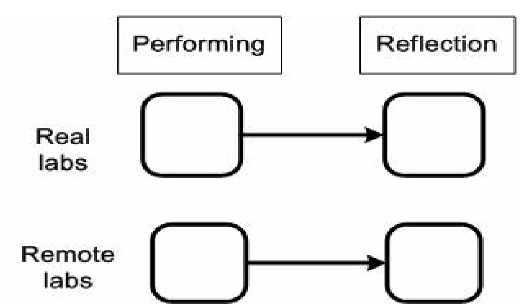

Figure 3. Group Collaboration Patterns: Hot Collaboration

Team III had a different collaborative environment compared to team I. In the real labs, these students had to meet in the classroom and run the lab together, which facilitated the real-time, co-located interaction pattern for the remaining part of the laboratory activity such as planning, discussing, etc. However, the situation might be different in remote labs where the convenience and availability for group meetings are decreased. Interestingly, Team III changed the way they communicate with each other in scheduling and planning for the writing, they used more remote communication and relied on e-mail and online chat, but they still met together to write the lab report. By which, they employed a "warm collaboration" strategy, indicating that the team members were not as closely attached compared to the members in the first team (see Fig 4).

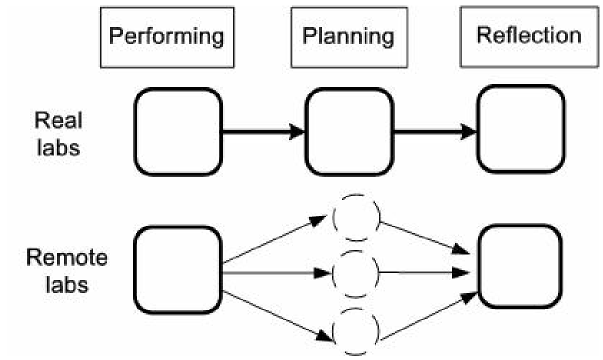

Figure 4. Group Collaboration Patterns: Warm Collaboration

The second team consistently worked remotely, asynchronously and individually. In a real lab setting, the members of team II had no interaction except for running the lab in the classroom and a face-to-face meeting to split up the work. In the remote lab, team II used e-mails to contact each other and to discuss issues only if necessary. The students in this team were only loosely connected and the work was divided up more on an individual basis than the people in the other two teams. The dynamics of group collaboration are shown in the following figure.

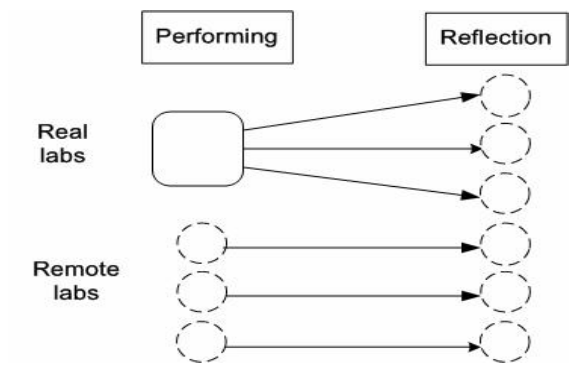

Figure 5. Group Collaboration Patterns: Cold Collaboration

Proposed Work

The result of preliminary studies indicates that group collaboration does change with the technology. In this section, I will introduce the research methodology designed for future work. A factorial experiment design will be used. Table II shows all the factors that might be involved.

A large-scale survey will be designed and distributed to collect the data. First, I will discuss the potential participants for this study and the procedures that will be used to collect the data. Second, measurements the variables will be explained. Third, I will address some potential covariates and confounds and how to them. Finally, I will discuss the methods used to analyze and test the hypotheses.

Topic	Hands-on Labs	Simulated Labs		Remote Labs	
Topic 1		S1	S2	R1	R2
Topic 2					

Table II. Factorial Experiment Design

Sampling and procedure

Participants are juniors in an undergraduate engineering course taught in Fall 2006 at the same university of preliminary studies. Students will be randomly assigned to different situations. Each participant has the chance to experience at least two different modalities of the labs of one topic. Data will be analyzed at the team-level. Participants will either be assigned or self-organized into teams. Each team has 3-6 students. The data-collecting process will go through three stages: questionnaire design, pilot test, and the formal survey.

Measurements

The variables will be measured using multiple scales, including Likert-type 0 to 7 scales (0 - strongly disagree to 7 - strongly agree) and some categorical scales.

Group collaboration patterns in the labs will be examined at two different levels. First, a laboratory activity is divided into three stages: initial phase, performing phase, and reflection phase. Second, group communication and coordination mechanism will be discussed at each phase as a combination of four factors: place, time, interaction frequency, and work style. These four attributes describe 1) whether the group is working at the same location (place) 2) whether communication between the group is in real time (time) 3) whether the group has frequent interaction (frequency), and 4) whether the group tends to carry out the work individually or collectively (work style). In particular, five questions are developed to describe group collaboration patterns: *My group always meet together to discuss our group work. I felt I had an immediate communication with my group. I felt I had frequent communication with my group. Everyone in my group makes equal contribution. Please evaluate your teammates' contribution to your group work in percentage (For example: A: 20%, B 30%, C 20%, D 30%).*

Building on the definition developed by Rafaeli and Sudweeks (1997), an interactive lab interface is defined as a lab environment which allows the students to have an active control and immediate communication with the laboratory apparatus. Accordingly, the level of interactivity will be measured based on the scales developed by Liu (2003): *I felt I had an active control over the apparatus; I could choose freely what I wanted to see; the lab experiment was very slow in responding to my request; I felt I had immediate communication with the laboratory apparatus.* In addition, objective measures are also used as a supplement to the subjective measures. Time-on task will be provided by the computer log and real-time observation.

The openness of the lab will be varied at two different levels depending on whether the procedures to do the lab are given or not (see table III).Another two-item scale is developed to examine the relational and physical distance among the group members: *My team mates and I l live close to each other. I knew my teammates very well before being in the group.*

Openness of the lab	Lab problem	Lab procedure	Answers to the problem
0	predetermined	predetermined	predetermined
1	predetermined	undetermined	predetermined

Table III. Openness of the lab

Students' learning performance will be assessed by subjective as well as objective measures. Specifically, perceived effectiveness of different labs will used as the subjective measure, and grades on a knowledge test designed by an educational expert and a lab report will be used as the objective measures.

The experiment design used in this study is effective in controlling most of the threats to internal validity but it is still vulnerable to some covariates and potential confounds. First, individual differences may play a role in students' learning performance. Second, team characteristics are another concern. The demographic characteristics of the team and team composition may have an impact on group collaboration. Third, the role of the instructor is not considered in my model which may confuse the final results. Covariant analysis will be conducted to control the effects of these confounds.

Data analysis

The data analysis is divided into three phases. In the first stage, I will perform an item analysis and factor analysis to examine the reliability of the data. The validity of the data will be assessed from three perspectives in the second stage: expert content review, discriminate validity, and convergent validity. Third, methodologies used to test the hypotheses will be discussed.

In particular, H1 is an exploratory hypothesis; category-based analysis, sequential analysis and cluster analysis will be used to identify collaboration patterns in different labs. In this study, a category is viewed as a multi-dimensional space. Four dimensions are used to classify students' collaborations with the physical instrument: authenticity, place, time and interaction intensity. These four dimensions describe 1) whether the laboratory instrument is real; 2) whether the students are working at the same location as the laboratory instrument, 3) whether communication between the students and the laboratory instrument is in real time and 4) whether the intensity of interaction between the students and the laboratory instrument is high or low. In addition, four dimensions are used to characterize students' collaborations with their team members: place, time, interaction intensity and collectivity. The first three dimensions are similar to the corresponding dimensions for student-instrument collaboration, whereas the last dimension deals with whether lab work is accomplished individually or collectively. Presumably, the relative similarity of the values of different dimensions can be measured, and so the distance between the members and nonmembers in one category can be quantified and distinguished (Nosofsky, 1989; Tversky, 1988).

Sequential analysis focuses on the temporal effects of sequence steps in order to show the relationships and dynamics between steps. It involves identifying the different steps of an activity. In this study, students' collaboration process with their team members was divided into four stages: running the lab, planning the lab, discussing the lab and writing the lab. The focus of the sequential analysis is to identify the relationships between the four stages and how the four stages relate to each other.

As a final step of pattern identification, cluster analysis will be conducted to test and reexamine the results of the category-based and sequential analyses. Cluster analysis focuses more on the relationships between the objects than on the properties of the objects. Based on the association between two objects, a decision on group membership will be made. Category-based analysis and sequential analysis will be performed using the data from observations and interviews, and the cluster analysis will be conducted based on the data from large-scale survey.

For H2, correlation analysis will be used to examine the relationship between different group collaboration patterns and learning performance. In addition, ANOVA will be performed to test if group collaboration patterns predict differently on learning performance (controlled for cognitive ability, LSQ and topic differences). To test H3-H5 with regards to the group membership, discriminant analysis will be conducted to test the degree of relationship between group membership and the set of predictors, the importance of predictor variables and the significance of the prediction. Hierarchical regression will be used to examine the mediating effect of group collaboration patterns hypothesized in H6. In particular, three regressions will be conducted. The first regression looks at group learning performance and all the independent variables; the second one examines the group collaboration patterns and all independent variables; the third regression tests group learning performance, group collaboration pattern and all independent variables. Based on the results from the three regressions, statistics can be calculated to examine if the effect of the independent variables on group learning performances dramatically decrease when group collaboration patterns are present.

DISCUSSIONS AND IMPLICATIONS

The application of new information technology in laboratory education presents a twofold effect on group collaboration: the technology used to design the physical lab interface and the technology used to support social communications. New technologies introduced in the labs may call for new forms of communication and coordination to augment or compensate for the potential isolation of students engaged in remote learning. In this sense, group collaboration might be more important than the technology to account for the variations in learning performance.

Using a pattern approach, I try to describe structure and generalize group collaboration activities in different lab contexts. Generally, students tended to minimize their effort to finish the task. As suggested by the interview study, it might be that not all the students will experience the three stages as I expected. The initial phase for preparation and planning is often skipped or becomes individual-based. So the learning in the lab most likely takes place during the performing and reflection phases. It might be that group effects are more important during the performing phase than the reflection phase. If the interaction with the laboratory apparatus is a crucial element for learning in the labs, running the labs as a group may motivate meaningful discussion and promote more behavioral interactions with the apparatus. It might also be that what is more important is the meta-cognition phase after the labs. Students who constructed the knowledge as a group are expected to be more effective than the individuals. However, the two phases might also be intertwined. Students may start to write the lab report and then go back to run the labs again to clarify some aspects of the lab.

In addition, the communication and coordination effects are also not very clear. It is not necessarily better performing the lab with all co-located meetings, synchronous media, frequent interaction, and collective work during all phases of a lab. Since the labs in this study are primarily designed for teaching the concepts taught in the class, lab activities will be cook-book style by nature. In this sense, group effect might be weakened because the benefit of brainstorming, sharing and learning from others is limited. On the other hand, however, group efforts do have rewards in terms of developing team cognition and facilitating future cooperation. Presumably, a balancing of individual and group work is probably optimal. For example, a warm group collaboration pattern with individual experimentation, group discussion using synchronous or asynchronous communication, and split-integration writing strategy might result in better performance than doing all aspects of the lab in a group-based environment. These questions can only be partially answered in this study and deserve more in-depth studies.

This research presents promising potential for future research. First, our literature review may advance the theoretical research on activity theory and patterns. The way group collaboration patterns in the labs are modeled may also be useful for other pattern research. Viewing group collaboration as an activity, technical contexts and social contexts are distinguished and how group collaborative activities are socially and technology-constructed are addressed. More importantly, patterns identified in this study will be of great value for both information systems design and organizational design. For example, patterns of communication and coordination mechanisms may shed light on groupware design in CSCW. Also, advice can also be given for organizational design in providing the guidelines for working teams to develop, regulate, and control their group collaborations while adapting to different contexts.

REFERENCES

1. ABET. (2005). *Criteria for Accrediting Engineering Programs*. Retrieved 10-25-05, 2005, from http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/05-06-EAC%20Criteria.pdf
2. Alexander, C., Ishikawa, S., Silverstein, M., Jacobson, M., Fiksdahl-King, I., and Angel, S. (1977) A Pattern Language New York: Oxford University Press.
3. Amponsah, K. (2003) Patterns of communication and the implications for learning among two distributed-education student teams, *SIGDOC'03*, ACM Press, San Franicsco, CA.
4. Barker, G. (2002) The effects of synchronous collaborative technologies on decision making: a study of virtual teams, *Information Resources managment Journal* 15, 4, 79-93.
5. Beal, D.J., Cohen, R.R., Burke, M.J., and McLendon, C.L. (2003) Cohesion and Performance in Groups: A Meta-Analytic Clarification of Construct Relations., *Journal of Applied Psychology*
6. *Journal of Applied Psychology J1 - Journal of Applied Psychology* 88, 6, 989-1004.
7. Canfora, G., Daponte, P., and Rapuano, S. (2004) Remotely accessible laboratory for electronic measurement teaching, *Computer Standards & Interfaces* 26, 6, 489-499.
8. Cooke, R.A., and Szumal, J.L. (1994) The Impact of Group Interaction Styles on Problem-solving effectiveness, *Journal of Applied Behavioral Science* 30, 4, 415-437.
9. Cooper, M. (2000) The challenge of practical work in an eUniversity-real, virtual and remote experiments, *Proceedings of IST2000*, Nice, France, 34-40.
10. Dewhurst, D.G., Macleod, H.A., and Norris, T.A.M. (2000) Independent student learning aided by computers: an acceptable alternative to lectures?, *Computers & Education* 35, 3, 223-241.
11. Dibiase, D. (2000) Is distance teaching more work or less work?, *American Journal of Distance Education* 14, 3, 6-20.
12. Domin, D.S. (1999) A review of laboratory instruction styles, *Journal of Chemical Education* 76, 543-547.
13. Edward, N.S. (2002) The role of laboratory work in engineering education: student and staff perceptions, *International Journal of Electrical Engineering Education* 39, 1, 11-19.
14. Engeström, Y. (Ed.) Activity Theory and Individual and Social Transformation? Cambridge University Press, New York:, 1998.
15. Ertugrul, N. (1998) New era in engineering experiments: an integrated and interactive teaching/learning approach, and real-time visualizations, I*nternational Journal of Engineering Education* 14, 5, 344-355.

16. Grant, A. (1995) The effective use of laboratories in undergraduate courses, *International Journal of Mechanical Engineering Education* 23, 2, 95-101.
17. Hara, N., Solomon, P., Kim, S., and Sonnenwald, D.H. (2003) An emerging view of scientific collaboration: Scientists' perspectives on factors that impact collaboration., J*ournal of the American Society of Information Science and Technology* 54, 10, 952-965.
18. Hegarty, E.H. (1978) Levels of scientific inquiry in university science laboratory classes: implications for curriculum deliberations, *Research in Science Education* 8, 45-57.
19. Herron, M.D. (1971) The nature of scientific enquiry, S*chool Review* 79, 2, 171-212.
20. Hogan, K., Nastasi, B.K., and Pressley, M. (1999) Discourse Patterns and Collaborative Scientific Reasoning in Peer and Teacher-Guided Discussions., in: C*ognition and Instruction,* 379-432.
21. Hollingshead, A.B., McGrath, J.E., and O' Connor, K.M. (1993) Group task performance and communication technology: A longitudinal study of computer-mediated versus face-to-face work groups, S*mall Group Research* 24, 3, 307-333.
22. Hutzel, W.J. (2002) A remotely accessed HVAC laboratory for distance education, I*nternational Journal of Engineering Education* 18, 6, 711-716.
23. Johnson, D.W., Johnson, R.T., and Stanne, M.B. (2000). C*ooperative Learning Methods: A Meta-Analysis.* Retrieved 01-25, 2006, from http://72.14.203.104/search?q=cache:aEULbGPZX04J:www.co-operation.org/pages/cl-methods.html+Cooperative+Learning+Methods:+A+Meta-Analysis&hl=en&gl=us&ct=clnk&cd=1
24. Kaptelinin, V., Nardi, B.A., and Macaulay, C. (1999) The Activity Checklist: A tool for representing the "space" of context, In*teractions 6,* 4, 27-39.
25. Kuutti, K., and Arvonen, T. (1992) Identifying Potential CSCW Applications by Means of Activity Theory Concepts: A Case Example, CSC*W 92 Proceedings, 2*33-240.
26. Liu, Y. (2003) Developing a scale to measure the interactivity of websites, Jou*rnal of Advertising Research 43,* 2, 207-216.
27. Magin, D.J. (1982) Collaborative peer learning in the laboratory, Stu*dies in Higher Education 7,* 105-117.
28. Magin, D.J., and Kanapathipillai, S. (2000) Engineering students' understanding of the role of experimentation, Eur*opean Journal of Engineering Education 25,* 4, 351-358.
29. Martin, D., and Sommerville, I. (2004) Patterns of cooperative interaction: Linking ethnomethodology and design, ACM *Transactions on Computer-Human Interaction (TOCHI) 11,* 1, 59 - 89.
30. Mayer, R.E. (2001) Multi-media Learning Cambridge, New York.
31. Mcateer, E., Neil, D., Barr, N., Brown, M., Draper, S., and Henderson, F. (1996) Simulation software in a life sciences practical laboratory, Com*puters & Education 26,* 1-3, 102-112.
32. McComas, W.F. (1997) The nature of the laboratory experience: a guide for describing, classifying and enhancing hands-on activities, CST*A Journal, Spr*ing, 6-9.
33. Nardi, B.A. (1996) Context and consciousness : activity theory and human-computer interaction M. I. T. Press, Cambridge Mass.
34. Newby, M. (2002) An Empirical Study Comparing the Learning Environments of Open and Closed Computer Laboratories, Jou*rnal of Information Systems Education 13,* 4, 303-314.
35. Nosofsky, R.M. (1989) Further tests of an exemplar-similarity approach to relating identification and categorization., Per*ception & Psychophysics 45,* 279-290.
36. Otero, V. (2001) The Process of learning about Static Electricity and the Role of the Computer Simulator, in: Unp*ulished doctroal disseration, S*an Diego State University.
37. Perlow, L.A., Gittell, J.H., and Katz, N. (2004) Contextualizing Patterns of Work Group Interaction: Toward a Nested Theory of Structuration, Org*anization Science 15,* 5, 520.
38. Potter, R.E., Cooke, R.A., and Balthazard, P.A. (2000) Virtual team interaction: assessment, consequences, and management, Tea*m Performance Management 6,* 7/8, 131.
39. Rafaeli, S., and Sudweeks, F. (1997) Networked Interactivity, Jou*rnal of Computer Mediated Communication 2,* 4.

40. Sander, F. (1999) The link of theory and experiment in lab work-an empirical investigation of students' action orientations and the use of graphic oriented model building systems in lab work, in: Phy*sics, U*niversity Bremen, Fachbereich.
41. Scanlon, E., Morris, E., Di Paolo, T., and Cooper, M. (2002) Contemporary approaches to learning science: technologically-mediated practical work., Stu*dies in Science Education 38*, 73-114.
42. Schummer, T., Borchers, J., Thomas, J.C., and Zdun, U. (2004) Human-computer-human interaction patterns: workshop on the human role in HCI patterns, CHI *'04 on Human factors in computing systems, V*ienna, Austria, 1721-1722.
43. Schwab, J. (1964) Structure of the Disciplines: Meanings and Significances, in: The *Structure of Knowledge and the Curriculum, G.*W. Ford and Lawrence Pugno (Eds.), Rand McNally & Company, Chicago, 6-30.
44. Shin, D., Yoon, E.S., Lee, K.Y., and Lee, E.S. (2002) A web-based, interactive virtual laboratory system for unit operations and process systems engineering education: issues, design and implementation, Com*puters & Chemical Engineering 26,* 2, 319-330.
45. Striegel, A. (2001) Distance education and its impact on computer engineering laboratories, Pro*ceedings of the 2001 31st Annual Frontiers in Education Conference, R*eno, Nevada, F2D.4-F2D.9.
46. Tversky, A. (1988) Features of similarity, in: Rea*dings in cognitive science: A perspective from psychology and artificial intelligence, A.*M. Collins and E.E. Smith (Eds.), Morgan Kaufmann, San Mateo, CA, 290-302.
47. White, D.R. (2004) Network Analysis and Social Dynamics, Cyb*ernetics and Systems 35,* 2, 173-192.