Making classrooms socio-technical environments for supporting collaborative learning: the role of personal devices and boundary objects

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Abstract: The emergence of low-price computers has made possible numerous new ways of classroom learning. The personal devices that are applied in a manner without interoperation with appropriate peripherals may interfere with face-to-face collaboration since the personal devices were design for personal usages. To improve the collaboration that takes place in small face-to-face groups in repeated episodes, we seek to strengthen relationships by encouraging non-verbal contact, which is known to be a key component to increasing intimacy in personal relationships. Through gathering the small group learning interactions in a collaborative learning scenario, this study proposed that classroom environments require, in addition to personal devices, special design of boundary objects to sustain and support social learning activities. An experimental classroom was developed with LCD displays and shared-display groupware. Analysis of student learning activity found that students working with only personal devices tended to learn together in a disjoint interaction pattern. Contrarily, in the environment with shared-displays as boundary objects students demonstrated a joint and coherent interaction pattern since they took more notice of the shared group work.

The power and limitation of one-to-one collaborative learning

Classrooms have been considered importance places where learning takes places in formal education. The emergence of low-price computers and wireless network has made possible numerous new ways of classroom learning. The notion one-to-one (1:1) was addressed to refer to the new learning scenario where students bring personal devices fitted with wireless communication capabilities into classrooms and apply these devices for various learning activities. Examples of these personal devices include Personal Digital Assistants (PDAs), OLPC (One Laptop per Child), Classmate PCs and Eee PCs. Some of these personal devices have been confirmed for their effect in improving classroom learning in the following ways: they connect the classroom to the outside world (Liu *et al.*, 2008); contextualize learning experience (Hsi, 2003), and act as extended minds (Clark & Chalmers, 1998) in the classroom. However, the personal devices that are applied in a manner without interoperation with existing peripherals such as displays devices and whiteboards in classrooms may interfere with face-to-face collaboration since the personal devices were design for personal usages (Liu and Kou, 2007).

The effect of personal devices on facilitating collaboration was specially addressed because these devices enable students to contribute personal experiences to collective thinking in classroom (Zurita & Nussbaum, 2004; Chen *et al.*, 2005; Roschelle, 2003). In addition, the availability of personal devices has changed the way how students managed their learning work and learning portfolios. At the time when personal devices were not widely affordable, students stored their coursework, reading materials, personal collections of websites and life notes in their tabletop computers. These portfolios were transferred and mirrored from tabletops to their laptops. The personal devices become the main repositories of personal work and learning portfolios. The personal devices may enrich the classroom learning since various artifacts collected across different contexts, locations and time were brought to classrooms that fulfill a seamless learning scenario (Chan et al., 2006).

However, the socio-technical environment through which personal resource, perspective, and work can be smoothly contributed, exchanged and integrated is not commonly supported in classrooms, despite the availability of personal devices. The classroom model that we commonly adopt was designed based on the requirement of instruction-oriented activity. Facilities such as backboard, podiums and the way seats were arranged mainly support passive learning scenarios in which students play the role of information receiver. It's rare in our classrooms that students contribute personal materials to the classroom that help to obtain a global integrated information set on which the class can reflect on. Information and knowledge sharing take places only in personal devices rather than in a place where all group members can jointly reflect upon. In addition, a lack of shared workspace may lead to loss of eye-contact and unawareness of visual focus (Scott et al., 2003). It was confirmed that naïve applications of personal devices do not guarantee improvement of interaction in classrooms and may lead to fragmented and tête-à-tête interaction patterns (Liu & Kou, 2007). Therefore, a socio-technical design that invites student contribution is required to support and sustain collaborative learning activities when students have their own computers in classrooms.

The concepts of socio-technical environments have been extensively applied in different areas to promote the collaboration and facilitate the mutual understanding of members. Socio-technical environments (Trist, 1981) refer to as the living entities that are capable of integrating computing infrastructures and participation processes supporting collaboration (Fischer, 2007). The socio-technical environments address the role of technology in facilitating knowledge sharing across boundaries between stakeholders and the role to improve congruence between participants to trigger social activities (Mumford, 2000). However, it is still unclear how the personal devices can cooperate with classroom entities to support the social learning activities and avoid the negative effect of these personal devices. It is therefore necessary to redesign classroom environments that may help to transform the classroom learning practice into collaborative learning experiences.

Different devices may afford different functionalities that can support a certain learning context. It is required to integrate different functions of devices to support learning activities in the physical environment (Bollen, Giemza and Hoppe, 2008).

Therefore, this study argues that instead of concerning only personal devices, the scope of one-to-one collaborative learning should extend to socio-technical environments that involve collaboration entities in the classroom. This study proposes an important classroom socio-technical entity, boundary object (Star, 1989), which should be included in classroom settings to facilitate collaborative learning. An experimental classroom was developed to support collaboration by using large LCD displays and shared display groupware as integral boundary objects to externalize the ideas of different participant. A group problem-solving activity was conducted in the classroom to examine the role of personal devices and boundary objects. By gathering and analyzing student collaborative activity, this study was conducted to explore what and how classroom technologies may cooperate with personal devices to augment collaborative learning experience in classrooms.

The socio-technical classroom

Trist (1981) first proposed the term socio-technical systems that address the close interplay and cooperation relationship between the social and technological systems. The socio-technical analysis of environments thus highlights the interweaving of social and technical factors in the way people work (Pan et al.,1998). From the social-constructivist view of learning, the role of classroom is not only to facilitate the acquisition of knowledge. It also has to be able to engage students in joint coherent knowledge construction activities with peers and teachers. Therefore, it is necessary to analyze how the technology affects the social activity in the classroom and identify what technical refinement should be made to best use personal devices.

In the context of collaborative learning, knowledge advancement involves a social process in which participating actors of different backgrounds cooperatively negotiate to reach convergent understanding from diversity of ideas (Roschelle & Teasley, 1995). One concept that can explain how workers/learners manage both diversity and cooperation is boundary objects. Boundary objects are shared repositories, externalized representation, work places, or communication methods through which all actors can interact by providing a shared reference that is meaningful within all actors (Star, 1989). For example, In Star's example, museum and libraries were boundary objects where all actors from different worlds could share, use and borrow artifacts for their own purposes. However, boundary objects do not always emerge naturally between all actors. "*The creation and management of boundary objects is a key process in developing and maintaining coherence across interesting social worlds* (Star, 1989, pp.393)".

Classrooms we customarily used today do not have special mechanism to help create and maintain boundary objects that appears in a digital form. It's not easy for all students to interact with each other by providing and accessing a shared reference to the digital artifacts in the personal devices. In addition, the fact that students work and discuss using only their own computers reduces non-verbal contact between students (Zurita and Nussbaum, 2004, Scott et al., 2003) which may create distance between members (Argyle & Dean, 1965). This study thus considers boundary objects that locate at the border between individual students and devices integral to promote and engage learners in collaborative activities. Through interacting with appropriate boundary objects, it is hoped that participants resemble a coherent organism to work with all aspects of artifacts.

To support collaborative scenarios with personal devices, the classroom model of this study includes shared display groupware as a critical boundary object of socio-technical environments (Fig. 1). Shared display groupware (DiMicco et al. 2004) were expected to facilitate collaboration by promoting shared understanding of distributed group artifacts and increasing awareness of partner actions since participants can get close to one another's center of visual focus with the shared display. The groupware displays either personal device screens or shared documents in their personal devices on the shared displays. Students can then clearly view the shared documents and personal device screens of others via the large shared displays that enable all participants to work together on the shared display. Additionally, instead of adopting flat-panel monitors, which are commonly adopted with computers, the workspace adopts 16:9 and 32-inch diagonal widescreen LCD displays. The LCD displays are more suitable for group learning than computer monitors, since they have wider view angles and screens. Since group partners work in the shared workspace rather than in personal devices, students are more

likely to conduct intimate behaviors such as eye contact and shared visual focus that sustain intimate social interaction.

Figure 1. A socio-technical classroom model with shared displays

The collaborative learning scenario and evaluation

The experimental classroom was first setup in 2005 and after then there were several courses were conducted in this classroom. This study collected and analyzed student learning activities in a collaborative learning scenario to investigate how the boundary objects between personal devices affect collaborative learning.

The participants were fifteen graduate students enrolled in the course "Statistics and Data Mining Techniques," at National Central University (Taiwan). Students solved the statistics problems assigned by the teacher collaboratively in the experimental classroom. The students were divided into three groups. The teacher presented problems, which the students had to collaborate to solve. To enforce personal accountability, students were asked to solve the given problems by themselves before discussing them with their peers. Group members then conferred with each other to organize a group solution. The interaction between group members and the process of discussion was observed in order to gain an understanding of how they interacted with the aid of personal devices and boundary objects.

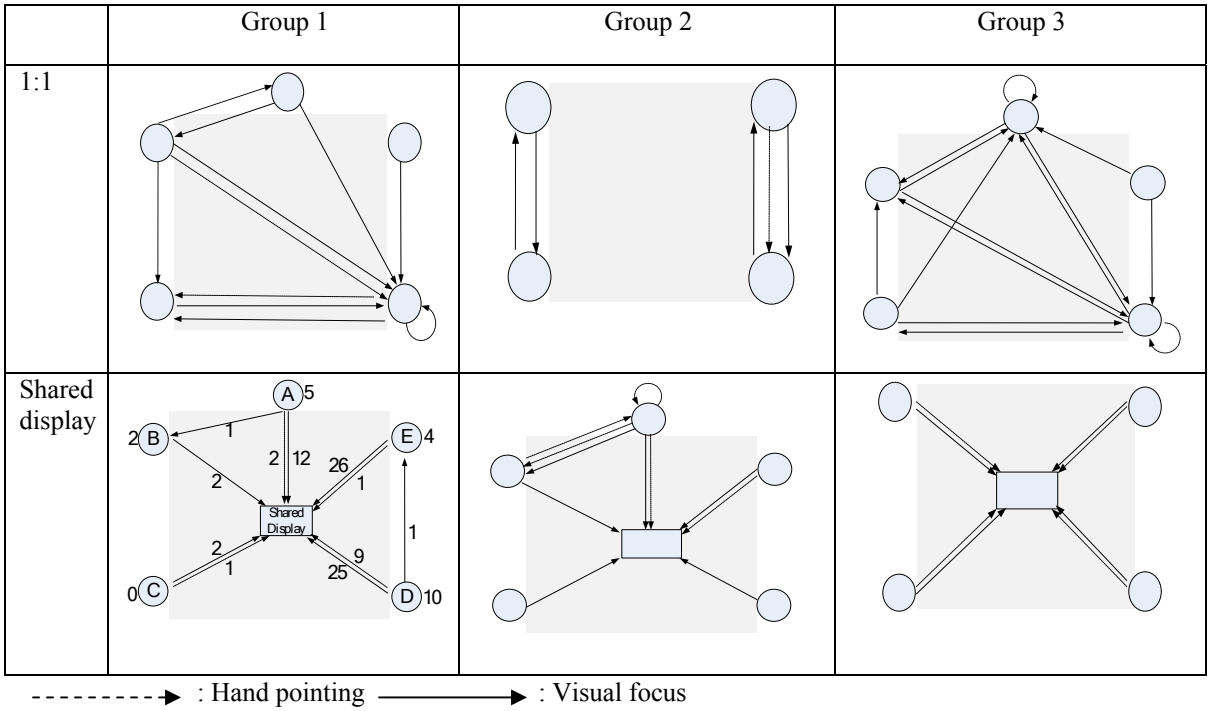

Figure 2. Non-verbal interaction patterns of groups in two different settings

This study assessed peer interaction as influenced by the use shared-displays groupware as the boundary object. Thus, the group problem-solving activity was carried out in two different environmental settings, namely 1:1 and Shared-Display. In the 1:1 setting, students used only the Tablet PC for both individual learning tasks and collaborative learning activities in the classroom. In the Shared-Display setting, students could utilize shared display groupware with personal devices in the group problem-solving activity.

To integrate non-verbal interaction with conversational analysis, this study analyzed the conversational and non-verbal events that occurred during the collaborative problem solving activities. Both conversational and non-verbal interactions were collected for further analysis. Because the interaction took place in a conversational format, the chronological order of the conversational utterances was analyzed to reveal the uptake relationship in conversation based on chat log analysis framework (Stahl, 2005). Two independent coders identified discussion threads, each of which represent a continuous set of connected utterances related to a topic since conversation topics kept changing. A new discussion thread was started when a student presented a new group development statement, position, or argument that was not related to previous discussion threads. In addition, this study also analyzed non-verbal interactions to reveal more details of interaction patterns since some social cues were not available in conversational records. These non-verbal cues included (1) watching personal devices, (2) pointing at personal devices, (3) watching the shared display, and (4) pointing by hand at the shared display.

Fig. 2 displays the non-verbal interaction pattern demonstrated by the three groups in 1:1 settings and in the environment with shared display. Each round node in the patterns represents a student. The number next to student node displays the number of discussion threads initiated by the student. In addition, an arrow pointing to another student indicates a student was looking at another student's personal screen. This study analyzed students' visual focus during each utterance of student conversation. The number attached to an arrow represents the frequency, i.e. the number of utterances, during which a student took visual notice on a certain device. Similarly, dotted arrows represent students' hand pointing behaviors.

The non-verbal interaction patterns revealed that interaction was largely affected by the positional configuration. In 1:1 setting, most non-verbal interactions occurred between students who sat next to each other. One exception is the interactions between student D and others in group 3 since the student took the leader role and initiated many discussion threads. The boundary objects, i.e. the shared displays, also profoundly affect student interaction patterns. Students in the shared display setting demonstrated rich hand pointing behaviors. On the contrary, students in 1:1 setting rarely demonstrated such behaviors. In addition, students demonstrated a joint and coherent interaction pattern since they took more notice of the shared group work. Students' visual focus concentrated on the shared display where the group works was conducted. The analysis of interaction threads also found that students exhibited different degrees of participation in the two settings. In the 1:1 setting, an average of 2.20 students joined in each discussion thread. In other words, most interactions occurred between only two students. In the Shared-Display setting on the other hand, each discussion thread attracted the participation of an average of 2.97 students, significantly exceeding the thread participation rate of the 1:1 setting (t=−5.777, p<.01).

Conclusions and implications

This study found students working with only personal devices tended to learn together in a disjoint interaction pattern in which only limited intimate social interactions were observed. On the contrary, students learning with each other through both boundary objects and personal devices demonstrated a joint and coherent interaction pattern since they frequently took notice of the group work and showed rich hand pointing behaviors. The difference in interaction patterns demonstrated by students in the two different settings revealed that boundary objects were critical because they help to attract students to interact with one another and engage in group activity, rather than to work alone with personal devices.

The development of low-price computers has made many new classroom learning scenarios possible. Although groupware applications could be built in the personal devices to improve classroom learning experience by enforcing social learning activities, the investigation into socio-technical classroom design that attracts and facilitates students to learning with peers remain limited. This study therefore applied a socio-technical approach to examine the interaction requirement of a classroom design that can cooperate with personal devices to support effective and lively collaborative learning. Through gathering the small group learning interactions in a collaborative learning scenario, this study proposed that, in addition to personal devices, classroom environments require special design of boundary objects to sustain and support social learning activities. It was found that the LCD displays, together with appropriate groupware in the classroom were useful to make classrooms a socio-technical environment to support group learning form both cognitive and affective perspectives. Designers of classroom technology may need to know the power and limitation of

personal devices. Different styles of boundary objects, such as the shared display groupware, may be designed to promote the face-to-face interaction in collaborative learning with personal devices.

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